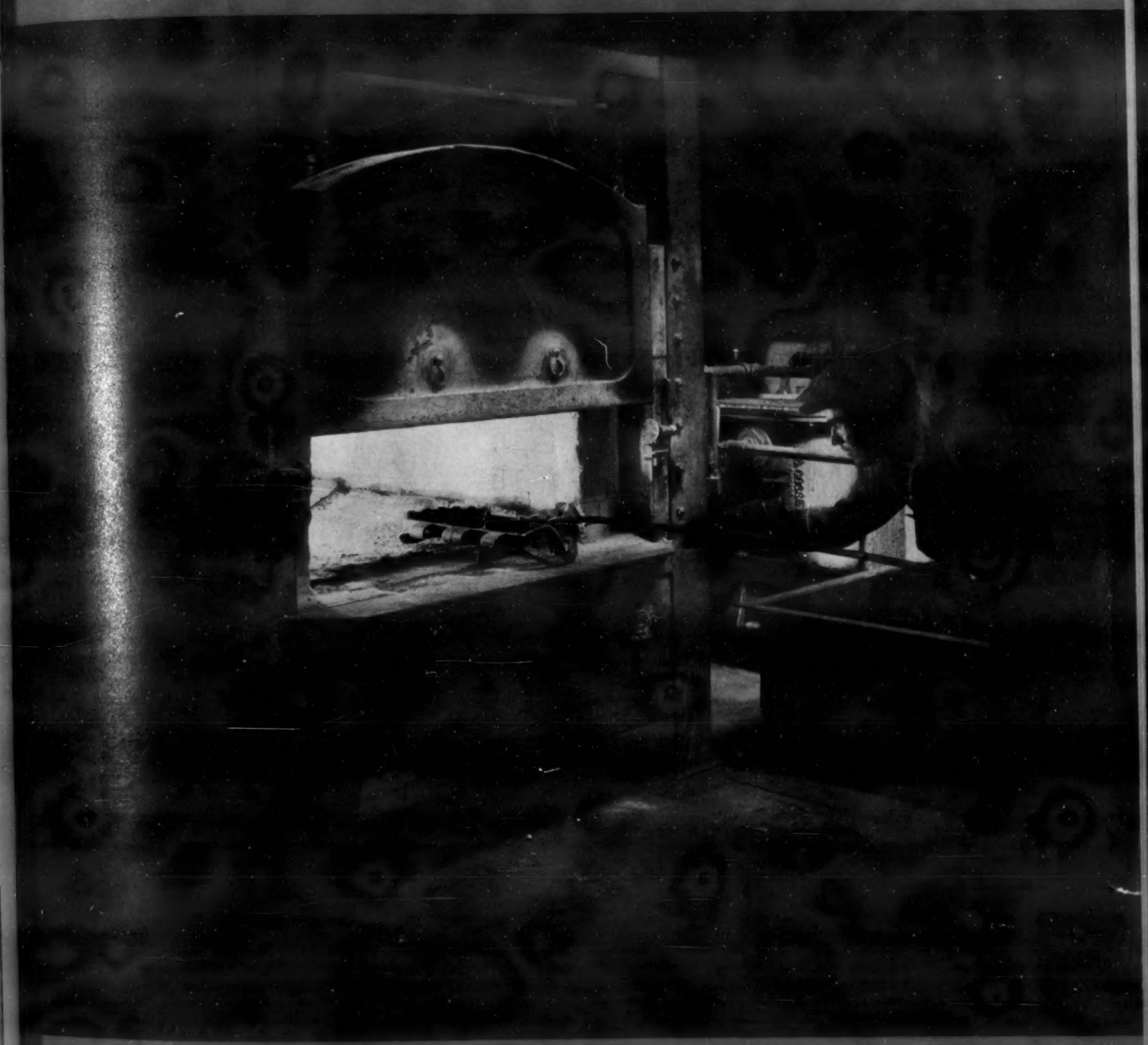
METALS & ALLOYS

The Magazine of Metallurgical Engineering

INCLUDING METALLURGICAL ABSTRACTS



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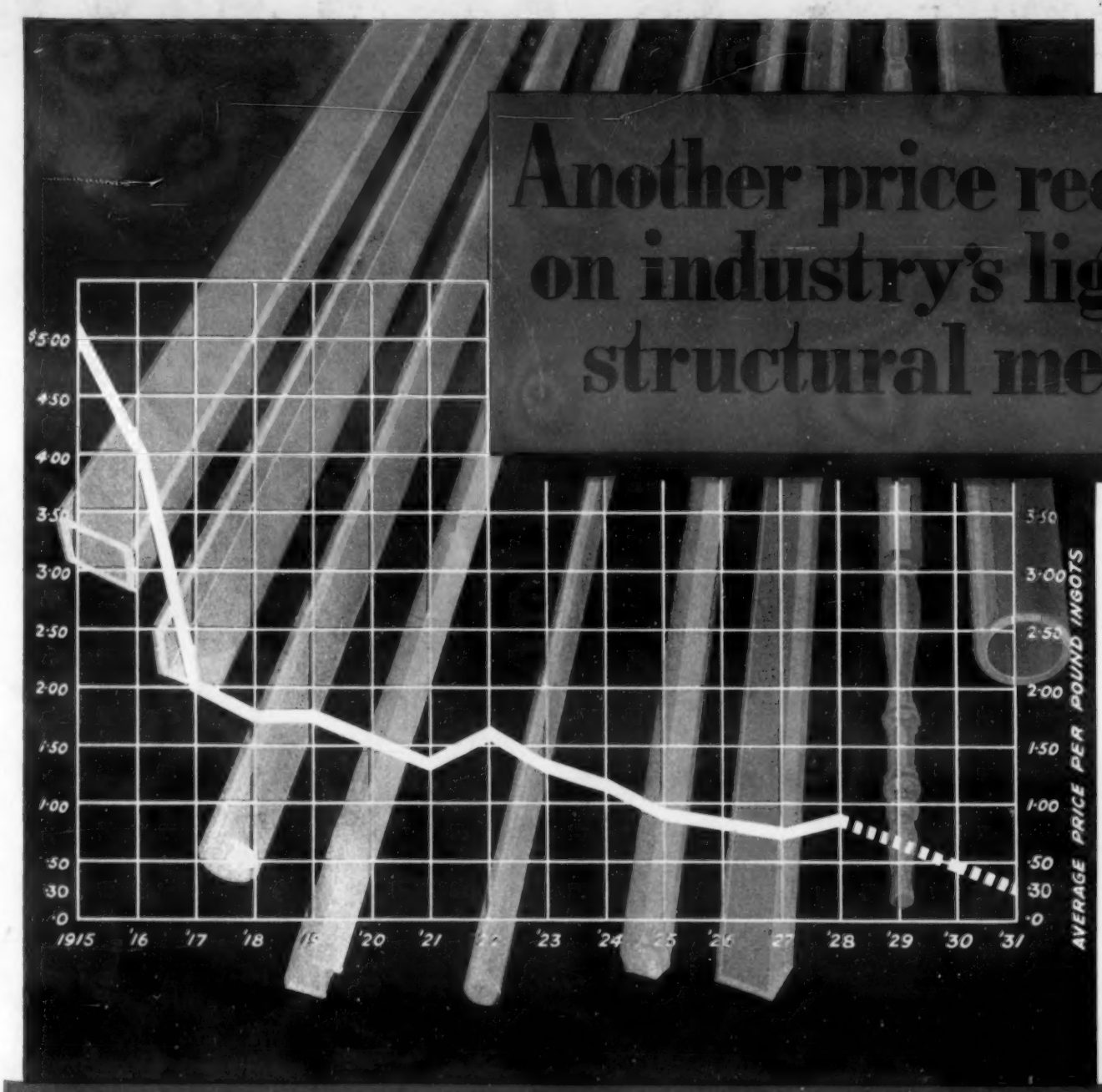

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The Magazine of Metallurgical Engineering

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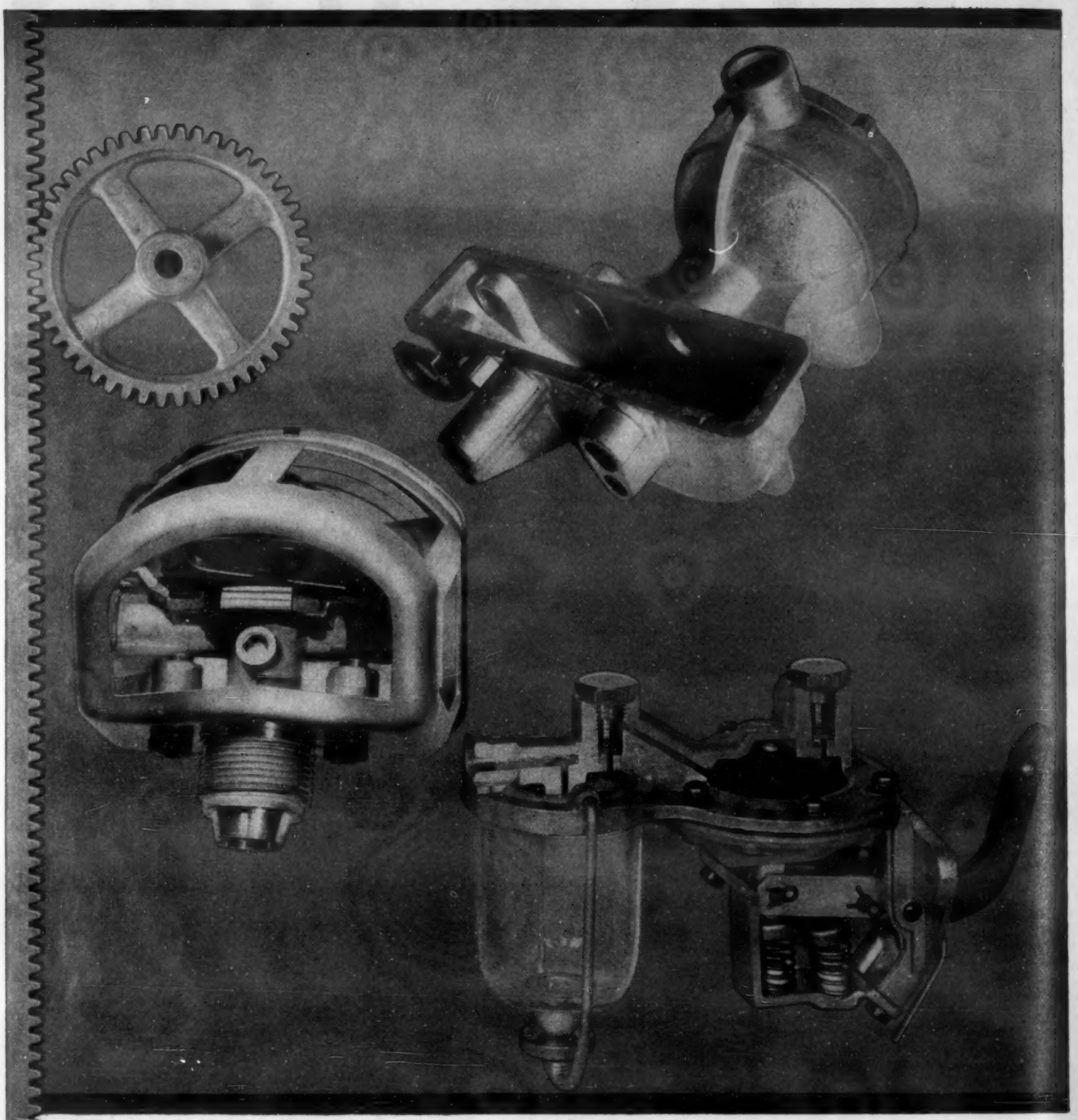

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EDITORIAL COMMENT

Heat Treatment

HEAT treatment in the modern sense is a pretty recent thing. We can ourselves remember when the text-books told us that steel below 0.20% C, did not respond to heat treatment, and when steel castings were all shipped green. We had been in metallurgical work some years when a pioneer aluminum metallurgist told us there was nothing in Duralumin, since cold worked aluminum alloys had far better properties. One would then have been laughed out of court if he had suggested that any copper-base alloys would respond to quenching and tempering.

In those days, the hardening and tempering of tool steels, of some medium carbon and of a very few alloy steels, chiefly nickel, and now and then nickel chromium, were employed, but the methods used would be considered horribly crude to-day. Pyrometry for heat treating was in a very embryonic state, and heat treating furnaces were just a burner and a pile of bricks.

With this issue we resume publication of feature articles in METALS & ALLOYS. It is the first of a series of reference numbers, each of which is well worth saving for future reference. The main theme of this issue is the heat treatment of metals and alloys.

Future issues will cover:
Forming of Metals and Alloys
Joining of Metals and Alloys
Finishing of Metals and Alloys

Malleable iron was annealed in much the present fashion, but the product was far less strong and far less ductile than it is to-day. Case carburizing was done, but gas carburizing was non-existent. Nitriding, of course, was not dreamed of. Heat treatment of cast iron was equally non-existent.

High speed steel had scarcely made its appearance. There was even then a demand for better steel for heat treatment, and the very first electric steel furnace in America was just being tried out.

All this was not in Civil War days, either. We are harking back to only about twenty-five years ago, i. e., around the real beginning of the automobile era.

On the scientific side, there were almost no teachers of metallography save the pioneers, Sauveur and Howe. Jeffries and Merica were still under-graduates. Burgess was then emerging from the chrysalis of a physicist into being a metallurgist. The iron-carbon equilibrium diagram was just appearing in some of the more modern text-books of physical chemistry; the metallurgical journals of the world that dealt with heat treatment could be counted on the fingers with several to spare; it would not have strained anyone's pocket book very much to buy all the books that dealt with heat treatment; and one could have read all the journal articles in that field in an evening per month, and still have had time to glance over the *Saturday Evening Post*.

There was then no need for an abstract service such as is now so essential a part of METALS & ALLOYS. Papers by Howe, Campbell and Waterhouse, dealing with heat treatment, had appeared in the Proceedings of the A. S. T. M., and one of these listed a dozen prior papers that had dealt with heat treatment of high carbon steel. The A. I. M. E. for 1906 had one article on heat treatment. The need for the A. S. S. T. had not yet arisen. Everybody in the world who could have entered into a scientific discussion of heat treatment would have made a very slim audience at a modern A. S. S. T. session, and those who were doing practical heat treatment would not have filled a very large stadium.

Scientific apparatus for metallurgical research was scarcely more advanced than was the furnace and pyrometer equipment of the heat treating plant.

Contrast this situation of a quarter-century or less ago, with the present knowledge and application of heat treatment, and with the present facilities for production, for control and for research, as shown by the articles in this issue of METALS & ALLOYS, and by the program of papers and the exhibits related to heat treatment at the National Metal Congress in Boston this month.

We wonder what changes we shall see in this line in the next quarter-century. Perhaps the curve of growth and improvement will show an even greater upward trend. Or will the curve become a closed loop like that enclosing the austenite field in some systems, and shall we be able, by some means not yet known, to produce new alloys of such superior properties in cast and wrought form that heat treatment will become obsolete and unnecessary?

We can be sure of one thing, the knowledge of alloys and of heat treatment, the exchange of that knowledge, and its practical utilization, will continue to increase, and our present "enlightened" state, on which we so pride ourselves, will appear as crude and embryonic in 1956 as the state in which heat treatment was in 1906 does to-day.

H. W. G.

Automobile Steels and their Heat Treatment

Great strides have been made in the utilization of steel for automobile manufacture. Early models were built with parts heavy enough to provide adequate factors of safety to allow greater latitude in materials and heat treatment than are permitted to-day. The steady increase in power of automobile engines, the demand for better performance and the intolerance of failures have made necessary the use of more durable materials. This has caused a trend toward materials possessing higher physical properties and toward heat treating methods which insure these higher physical properties in every piece treated.

It has long been recognized in some quarters that two heats of steel of similar analysis and falling within limits of a certain specification might not be the same physically or respond alike to the same heat treatment. There was a time when those who appreciated this fact assumed that it was a necessary evil and took steps to vary heat treating processes to get the desired result with each heat. A case in point was the practice at a certain plant making army rifles during the war. Every heat of gun barrel steel received was subjected to tests to determine what changes in heat treatment were necessary to obtain the physical properties specified for this part. Large quantity production of small parts which go to make up automobiles or other comparable articles of commerce, made it apparent that such methods are wasteful and that the steel for a given part should be of such uniformity as to make unnecessary the frequent adjustment of heat treatments to meet the changes in steel quality from heat to heat. The cause for variation in response to heat treatment may be resolved into variations in chemical analysis from a little under the minimum to a little over the maximum specified for each element on the one hand and variations on the other hand in physical quality as a result of differences in the method of steel manufacture and quality of raw materials.

The first steps taken toward relieving this situation were directed at the more tangible of the two causes with the result that instead of steel being bought on specifications calling for a range of 10 points in carbon, a limit of 5 points was set. The use of steel coming within this narrow range is of great assistance in obtaining more uniform results and makes possible continuous heat treatment without juggling temperatures to accommodate changes in composition from heat to heat of steel. An intimate knowledge of how variations in other elements such as manganese, nickel, silicon and so on affect proper heat treating temperatures and properties obtainable, in conjunction with the desire to have one heat treating temperature for all heats of steel of a given specification, is responsible for the limits set in steel specifications as they are to-day. This type of control simply increases the assurance to the engineer that parts so made have the physical properties upon which the design of the part was based. This demand for greater uniformity has had its influence upon heat treating equipment to the extent that those furnaces and control methods are used which give the least variation from the optimum temperature and atmospheric conditions. In the case of large capacity furnaces this has made the box type furnaces give way to the continuous furnaces. Electric furnaces are used to attain this uniformity and the design of gas and oil fired furnaces has been improved because of these demands.

With all these aids to uniformity, there still remains the question of quality variation of raw material. The McQuaid-Ehn or similar tests are being resorted to more and more to detect such variations. Grain size specifications are becoming more common in purchasing steels not only for carburizing steels but also for the higher carbon steels. From the time when the first efforts were made to control grain size and cementite condition in steels, considerable progress has been made. We have acquired a general knowledge of the qualitative nature of properties associated with these different conditions; but there is a dearth of quantitative information on physical properties after heat treatment associated with variations in grain size and normality in the steels commonly used for automobile manufacture. There is an abundance of data in the literature comparing physical properties of different grades of steels, but not enough relating to variations encountered in any one grade of steel over a large number of heats made by different manufacturers.

Another factor affecting the uniformity of heat treated steel products is the type of scale formed upon heating in furnace atmospheres. The amount of scale formed and the tightness with which the scale clings to the steel during quenching influences the degree of hardening obtained. Improvement in hardening has been obtained by the use of controlled atmospheres in gas and oil fired furnaces, by the use of electric furnaces and by the use of special fuels like butane. Here again we need some quantitative information upon the exact influence of heating atmosphere upon the character and amount of scale formation and its influence upon the degree of hardening obtained.

The demand for better quality in automobile parts at the same or lower cost, or lower cost without sacrifice of quality, has had its influence on materials and heat treatments. This trend may be illustrated by a few examples. Nickel molybdenum steels have replaced 5% nickel steel in some instances on account of lower material and machining costs. Grain size control in carburizing steels has made it possible to obtain uniformity in carburized gears quenched from the carburizing box thus simplifying the treatment and improving the properties. SAE 1300 series manganese steels have found use in places where more expensive steels were formerly used. Nitriding has found but few applications in automobile manufacture. Where high surface hardness is needed, the requirements have been met by adjusting the design to make lower cost material satisfactory.

Anything that can be done toward the procurement of a more intimate knowledge of the possibilities of materials and what methods are necessary to get the highest degree of uniformity with these materials so that better cars can be furnished the customer at no increase in cost seems to be a prevalent desire. A. L. B.

"Brains"

When Dr. C. B. Dudley, the first chemist of the Pennsylvania Railroad, and probably the dean of railroad chemists, spoke before the Chicago Section of the American Chemical Society some twenty years ago, he referred to his first arguments with his superior. He told him that he needed glassware with which to work and requisitioned some beakers, but his requisition was turned down with the remark that their former restaurant, now defunct, had been well supplied with tumblers and glassware and that he could use all he wanted.

Visiting some of the modern research laboratories now, one is forcibly reminded of the marvelous change which has taken place in the viewpoint of the business executive toward testing and research laboratories. It was not longer than twenty years ago that any old dark corner or a space under some stairway was considered good enough for the "chemist" and his laboratory. He was expected to work with dust and smoke pouring in upon his one balance, his beakers and test tubes, and often his results and even his opinion were given just about the amount of consideration that would be expected from a boss who had him work under such adverse conditions.

Now much of this is changed, though only the start has been made. New and specially designed buildings are put up to house the laboratory, and the workers are given every consideration in the way of proper lighting, ventilation, freedom from dust and smoke, while the latest and best of apparatus with which to work is furnished them. Even in the organizations which long had the reputation of being "hard boiled" toward their technical men, this different policy now prevails. New research laboratories, adequate apparatus and sufficient technical help are available and all that the chief chemist, the chief metallurgist and the director of research now have to pray for is the "brains" to use their forces to the best advantage. L. W. S.

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The Need for Critical Summaries

In recent years we have seen a tremendous increase in scientific output, as measured by the number of papers published; this increasing output is largely the result, direct or indirect, of the continuously greater interest of industry in scientific research. A large proportion of these papers contain little that is original or new; many of them deal with questions already substantially settled—which may or may not be known to the author—others are devoted to the promulgation of erroneous beliefs or convey to the reader only a part of the truth. The consequence is that, in order to ascertain just what is now known about a topic, one must in so many cases read through an enormous amount of material, much of it irrelevant, and is lucky if one does not meet with major contradictions or inconsistencies. The not infrequent result is that in spite of a great deal of work one may not be able to reach an adequate basis of judgment and may even be led to wonder as to how many of the statements can safely be taken at their face value. We have all been accumulating observations, in part incompletely controlled even though frequently designated as facts, much faster than we have learned to digest them and assimilate them into our system. And in no branch of physical science is this uncertainty as to experimental evidence and the admissible deductions from it greater than in the branch concerned with the study of metals.

The situation calls for a greater number of more critical reviews of specific topics, aiming to point out what may be regarded as established and what is still uncertain or unknown, and thus to suggest where experimental work is needed. Recently the need for such critical summaries has begun to be more widely recognized; for instance, in the Alloys of Iron Research project, sponsored by Engineering Foundation and supported, through the coöperation of the American Iron and Steel Institute, by industry, and in the aims of this magazine. But much remains to be done, and we cannot have too much critical discussion of the many questions which still remain so puzzling to the practical metallurgist. It would seem, therefore, that progress in the science of metals, and in its application, will be aided by any one who, having arrived at a viewpoint from which a group—even quite a small group—of phenomena appear to be akin, will take the trouble to present his view of the matter in a reasoned, critical, concisely written paper. As another step in this direction, we should encourage authors of papers describing an experimental investigation, to fit the results of their survey into the map of the general region, and to attempt to indicate what further surveys are needed to make the map a thoroughly satisfactory guide. To do this would enhance the value of the work to the general reader, by enabling him more easily to grasp its significance; it would not necessarily make papers longer in general, if the author (or editor) would see to the abridgment of the purely experimental details and results by the exclusion of those which at this date are unnecessary; and it would tend to hinder publication of certain papers by exposing their lack of significance. These are consummations devoutly to be wished, and far from easy of attainment; let us at least recognize more widely the necessity of more critical summaries, and strive to secure them. J. J.

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Sweep out the Nooks and Corners

During the trough of the period of depression, we asked a research man connected with a large steel company whether his laboratory found much to do while the plant, like other steel plants, was working at some 50% of capacity. He said, "Oh yes, we're sweeping out the nooks and corners."

This expression well characterizes the great mass of our present-day progress in science and engineering. It is given to few to make epochal discoveries and in-

ventions. Most progress comes from improvements upon materials and processes already familiar, but which need to be more closely controlled in order to achieve a little better uniformity, a little higher quality. Even the brilliant basic discovery never works just right till many people begin to use it, and start patiently to iron out the "bugs" on this and that detail.

Certainly intensive study of little things is worth while, especially the application of new tools for, and methods of, research to those time-honored methods of metallurgical production that have been carried out in the same old way so long that it scarcely occurs to us to question whether that is really the right way.

It is just as important to maintain uniformity of present products by the exercise of greater care and cleanliness, by the development of automatic methods of control, by working out and applying adequate tests and specifications for the raw materials and for the product itself, by saving a few pennies here and a few there by improved manufacturing methods as it is to develop new products or those of new and striking properties. It is not so spectacular to plug along on the minutiae as it is to break new ground, but it is equally important for future dividends.

But in all our research we find it necessary to repeat older pathfinding work in greater detail, with more modern apparatus and more care, in order to get data accurate to another place of decimals, for we need more refined data. No research problem is ever finished. The farther we go, the more details appear for attention. As major difficulties are solved and big variables are brought under control, smaller variables that were previously obscured by the larger variations must be given attention. Truly we are in an era when much of our effort has to be devoted to "sweeping under the bed," cleaning up the minor problems we may not even have recognized before.

Fortunately, most forward-looking firms kept their research staffs intact during the period of depression, and have done a good deal of cleaning up on plant troubles that needed solution, but could not be studied in a period of intense production without hampering output. The more fundamental research problems may temporarily have received less attention, but there is a place and a time for both types of problems. The plants that have seized the opportunity to look into the nooks and corners may find the depression a blessing in disguise, enabling them to produce more efficiently when production does pick up. Those who at the first hint of lowered production, drop the men capable of sweeping under the bed, will always find it more difficult to compete when orders again begin to be distributed.

H. W. G.

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Technical Society Committees

The bulk of the work of most of our scientific and technical societies is necessarily done by committees and sub-committees. The work has to be done if continued progress is to be made, and more committees are constantly formed.

Committee work is generally undertaken because it has a bearing on the activities of the firm or organization with which the committee member is connected, and is undertaken with the full approval of the member's employer. But the committee work is always a side issue; the member has a full-time job to attend to, and the committee activities are added ones. So, ordinarily, the committee work is, in effect, done on the member's own time, for if he does committee work in office hours, it means that he takes other work home.

Hence, he must have a real personal interest in the work of the committee, or he will not be a worker. And a non-working committee member is a drag on the whole committee. At any meeting which he happens to attend, much time must be spent posting him on things he would be in touch with had he been a worker. It is often necessary to persuade him of the necessity for past committee actions that have been previously well thrashed out, before his point of view approaches that of the active workers. Yet his vote counts, and he must be dealt with. The most pressing need in many of the older committees is a pruning of dead wood.

By the same token, most committees are too large. They start out by appointing, for the sake of their names, men of reputation and standing, whose personal interest in the committee is slight, who cannot gracefully decline appointment, but who never really expect to be anything but a figure-head. Such men may be wonderful workers when they are interested, but terrible flops when their interest is perfunctory.

One cannot blame such a man for failing to be active, for the work of a live committee does take time, and added to all his other duties, the work might be the last straw on the camel's back.

We can properly blame him for appearing to accept a responsibility, but the real blame rests on the society officers or the committee chairmen who force an acceptance from a reluctant appointee.

Names are far less important than ability and interest. In most fields there are second-line men, comparative youngsters, who indeed often know more about the particular subject on which they are working than their chief can. Their attention and interest are not so ramified that there would be anything perfunctory in their committee work. Indeed, such men would generally prize the opportunity to rub shoulders with other committee members and would count their own time put on committee work as well spent in building up a professional acquaintanceship and reputation. A committee made up of a few older men, for experience and balance, choosing those who are so vitally concerned with the subject that they will take the job seriously, and of a good proportion of active youngsters, "comers," for verve and speed, will have maximum effectiveness.

Not only would a little more attention to this principle liven up the committees, and be helpful in the broadening of the youngsters, but it would be helpful from the point of view of the society. The old-timers will drop out sooner or later, and others must be coming along to take their places. The wheel-horses should gradually be turned out to pasture and the colts harnessed.

H. W. G.

(Continued on page 116)

Production and Heat Treatment of ALLOY STEELS

BY R. A. BULL*

Apathy Prior to World War

AFTER an existence of nearly fifty years in America, the steel casting industry began for the first time to take a constructive interest in the manufacture of special steels for castings, almost coincidentally with the beginning of the World War. While there was an appreciable amount of austenitic manganese steel castings produced in this country twenty years ago, the effort then devoted to the production of unusual steels in the foundry was insignificant, except in a few plants. War-time demands on the steel casting industry brought home to it the conviction that many designers of industrial equipment would soon require steel castings having more impressive combinations of physical properties than were being regularly produced.

The former reluctance of the industry to pioneer in alloy steel manufacture was partially due to the somewhat passive attitude of many consumers, in respect to reduction of weight, barring the progressive spirit that prompted users of certain railroad and other equipment to resort to steel castings, in obviously necessary substitutions for weaker materials. In many cases, when such changes were made, the engineers were satisfied, displaying no keenness about further weight reduction; failing to realize, perhaps, that additional economies were attainable from the higher yield point, tensile strength and other physical test values, already demonstrated as typical of alloy steels. Prior to 1918 there was no generally manifested tendency to extend the policy of sectional reduction.

THE commercial development of alloy cast steel has advanced further than many people realize, but is due to advance still further. This article makes the interesting comment that, since electric melting in relatively small furnaces is now so common, it is economically possible to experiment commercially with special alloy steels, while if they had to be made in large open-hearth heats, the cost of experimentation would be prohibitive. Under present conditions we may expect an increasingly rapid development of special cast steels and of heat treatments calculated to bring out their best properties, for special types of service.

The Beginning of a New Era

In several respects the World War greatly stimulated metallurgical effort in American steel casting plants, however disastrously it resulted in many ways. For one thing, it thrust physical testing machines into more extensive use. When the conflict terminated, many foundries began to experiment in the manufacture of special steels. Some such plants had experienced difficulty in meeting Army specifications. Naturally, all of this brought about marked improvement in heat treatment practices, whether such treatments were applied by simple or by elaborate procedures. Furnace builders diligently applied themselves to the new order of things with much success. The more effective use of oil and gas was accompanied by the adaptation of electrically generated heat. Many obsolete annealing ovens were scrapped. Considerable sums were expended for well designed heat treating furnaces, and for pyrometric equipment necessary for their proper operation. And the result was the gradual acquisition by the steel casting industry, of heat treating equipment which now compares favorably with that used in any other branch of manufacture.

About the time of the World War, there began the striking, continuous development of relatively small industries, which has been commented on by economic historians. In each of many of these new industries, comparatively small tonnages of steel castings were needed. In some instances, as, for example, in automotive lines, greater resistance to stresses was required, in conjunction with smaller metal sections.

This industrial development, by greatly increasing the number of individual demands for relatively small tonnages of steel castings, brought about the installation of many electric arc furnaces in the steel casting industry, which had previously been dependent to very large extent on individual purchases in large tonnages. As the number of electric melting units became greater, and as there were thus automatically provided means for the manufacture of steel in small quantities, there was made available to the steel foundryman a much better opportunity than he had had before for producing alloy steels, simply because of the relatively small capacity of the furnace employed. Previously many progressive steel foundrymen who were desirous of experimenting with special steels for castings had been unable to secure orders for alloy steels in such substantial tonnages as would make manufacture practicable in their relatively large open-hearth furnaces. It happened that a great many industries consuming steel castings in moderate tonnages, became seriously interested in ascertaining what benefits could be derived from alloy steels. As a result, the demand collectively considered, for cast alloy

* Director, Electric Steel Founders Research Group, Chicago.

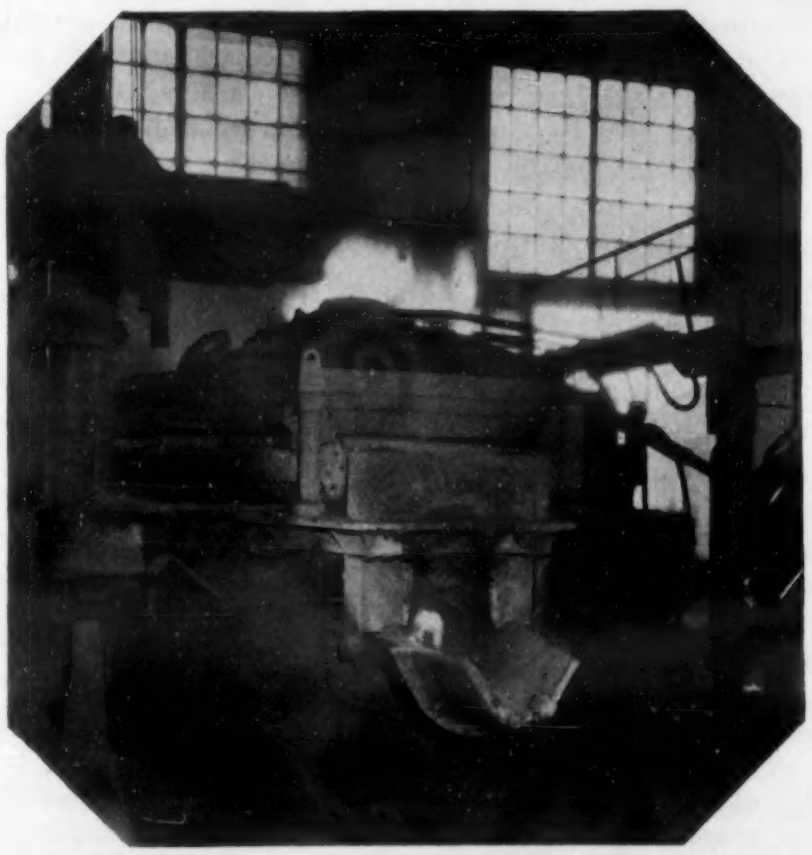
steels, increased coincidentally as the average tonnage demand per consumer became smaller.

Statistical Data Showing Demand Tendencies

Looking back a few years, we find some statistics which are interesting as showing the extent to which the industry as a whole has utilized the alloy product of the steel foundry. According to the American Iron and Steel Institute surveys which, in respect to this product, began with the year 1910, it is not superficially apparent that war-time use, with its extraordinary demands on the steel casting industry, had any immediate significant influence. The effect of seriously considering for each industrial purpose the properties approximately ascertained in the laboratory, was to come later. The result is seen clearly in the statistical data for 1923. The figures below show the tonnages of alloy steel castings, for the ten year period ending with 1930. These data are expressed in net tons, translated from the gross ton figures reported by the Institute, in its annual summarizations:

1921— 45,086	1926—163,633
1922— 66,196	1927—163,345
1923—103,286	1928—190,045
1924— 96,262	1929—216,071
1925—126,093	1930—141,264

It may be remarked in passing that in 1910 the output of alloy steel castings in the United States was less than 33,000 net tons. The tonnage figures become more interesting in showing the progressive proportionate increase of the special foundry steels when some percentage figures are calculated. For example, alloy steel castings made in 1910 represented but 3.1% of the entire output of the industry. Ten years later, the proportion was 5.5%. Last year the showing was 11.4%. Of the tonnage representing this proportion, open-hearth furnaces produced a little less than and electric furnaces produced a little more than 48%, the remaining 4% being made in converter foundries.



Three-ton electric arc furnace. This is the size and type of furnace that is utilized for most of the alloy steel castings produced to-day.

At present the steel casting industry is well equipped with melting and heat treating facilities to serve all other industries with special steels to suit peculiar conditions of service. Yearly, many manufacturers who have previously purchased substantial amounts of castings restricted to the common grade of steel, are finding it advantageous to utilize special steels, whereby many of them have materially reduced the weights of parts and have lengthened the life of equipment.

The writer believes the proportion of alloy steel castings to total steel castings will increase noticeably from now on, because economy promises to be stressed emphatically hereafter. Maintenance expense will be sharply scrutinized by purchasers of all kinds of equipment. It will be the cost in the long run, and not the purchase price only, that will govern material selection. In many cases, this will necessitate the use of alloy steel castings.

Impressive Properties of Common Steels

The average purchaser of steel castings ordinarily thinks restrictively of the employment of one or more special alloys, when he considers the product of the steel foundry in connection with combinations of physical properties that are noticeably more impressive than those required in current specifications for carbon steel castings, adopted by the American Society for Testing Materials. Some consumers do not realize that significantly improved properties may be developed in ordinary grades of steel used for castings, by judiciously selected heat treatments. Liquid quenching provides a very useful detail of treatment adaptable to carbon and to numerous grades of alloy steels. Many types of steel castings may be water-quenched or oil-quenched without injury, when proper care is exercised in the withdrawal of the material from the annealing oven at the correct temperature; in the skillful immersion of the castings in the cooling bath; in maintaining the quenching medium at a suitable temperature; and in withdrawing the parts from the tank at a temperature above that point which might produce quenching cracks. Naturally, these defects are more apt to occur when great sectional inequalities exist than when thicknesses of members are fairly comparable. In the case of valve castings, present A. S. T. M. specifications prohibit liquid quenching, obviously because many such parts have very thick flanges jointed to very thin body-walls. It will illustrate the writer's references to significant physical properties obtainable from common or carbon steel by special heat treatments, to mention characteristic results advertised by a manufacturer of good standing who states that he gets tensile strength values ranging all the way from 80,000 to 125,000 lbs./in.^{2}, accompanied by reductions of area varying from 60 to 15% in cast carbon steel, containing no special element, following water quenching and drawing. These differences in tension test results are said to depend entirely on the temperature of the drawing treatment. When liquid quenching is skillfully applied, it is apparently adaptable to many types of castings.

To aid the intelligent comparison of some of the figures quoted above with those obtained in testing the ordinary variety of steel used for castings for most miscellaneous purposes, it may be stated that the customary soft grade of carbon steel manufactured to-day in jobbing foundries regularly shows ultimate strength

values in the tension test of approximately 75,000 lbs./in.^{2} Steel of this grade, given a simple normalizing or full annealing treatment, unaccompanied by any supplementary treatment (such as a liquid quench or a draw) readily meets the minimum requirement of 70,000 lbs./in.^{2} in many commercial specifications. Such material has good ductility and machines easily. It is a dependable grade of soft cast steel and satisfactorily meets many industrial requirements.

Comments on Varieties of Alloy Steels

The manufacture of alloy steel castings rather easily divides itself, in designation of classes, despite some differences of opinion as to where to draw the line between common steel and alloy steel. These disagreements relate mainly to a grade of metal now being produced in relatively large casting tonnages yearly, which has found favor in many industries where something better than ordinary steel is needed, but where circumstances have not seemed to justify a cost price applicable to a grade of steel that has for several years been more or less generally recognized as an alloy grade.

This cheaper grade of alloy steel for castings has been termed by some "medium manganese," and by others "pearlitic manganese." The metal usually has a manganese content between 1.25 and 1.50%, as compared with a manganese content around 0.75%, customarily found in the ordinary or common grade of steel put into castings. Such steel has been found very satisfactory for many applications, where greater resistance to service stresses is needed than is afforded by the old-time product of the steel foundry.

Once we depart from the field of medium manganese steel, and enter the realm of steels universally regarded as being of alloy grade, we encounter fewer differences of opinion as to classification by name. Here we have a variety of alloys, such as chromium, nickel, vanadium, molybdenum, tungsten and other elements, each frequently utilized in relatively small proportions, and produced in combinations, sometimes with, sometimes without normal percentages of the customary elements, physical properties of the greatest importance to many consuming industries.

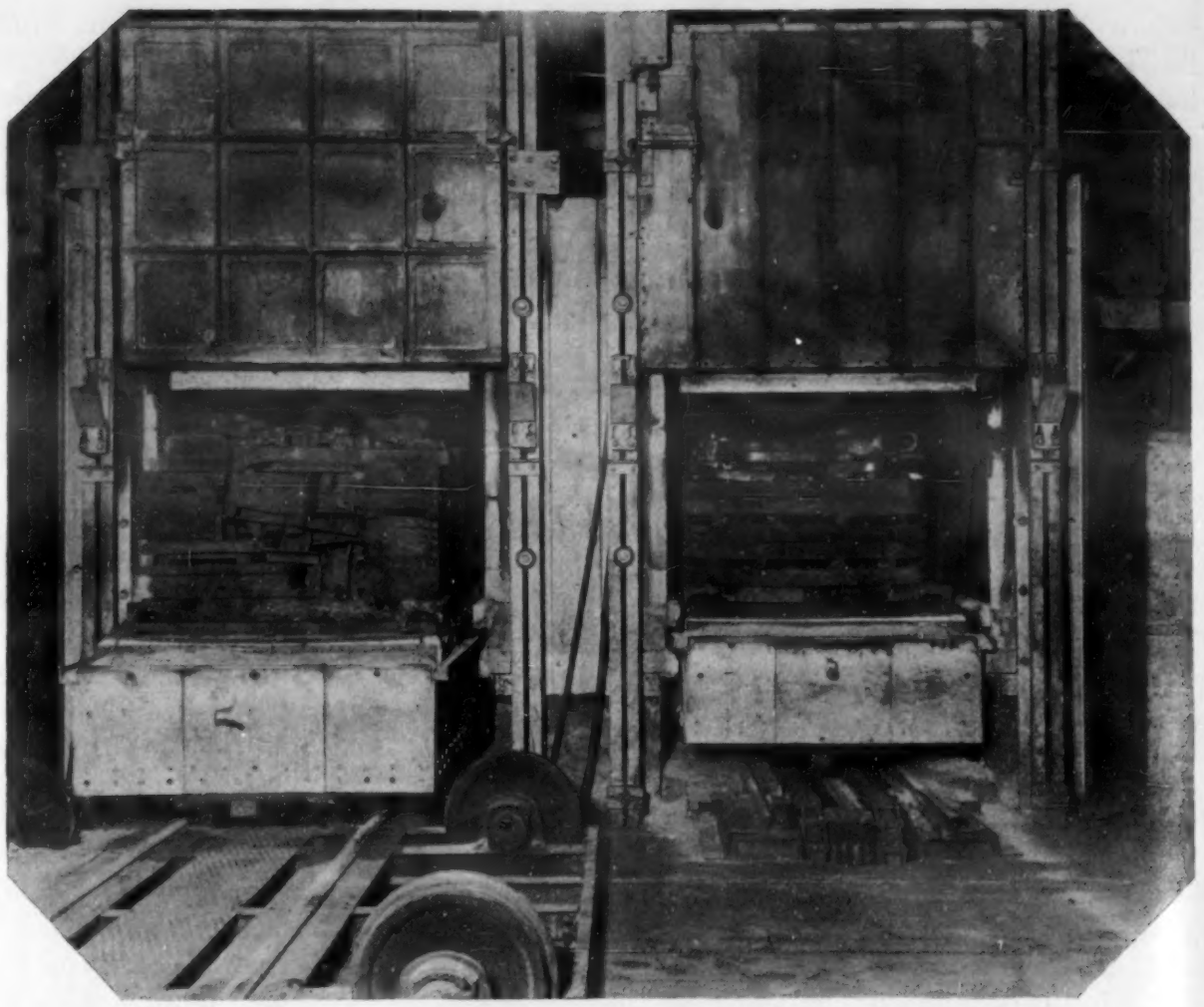
It has not been widely appreciated by consumers that the effects of a given relatively small percentage of an element such as nickel, or chromium, or molybdenum, introduced in conjunction with a normal percentage, say of silicon or manganese, are vastly different from the effects of the same percentages of these special elements when used in conjunction with unusual proportions of the two commoner ones mentioned. Silicon and manganese have demonstrated themselves to be important factors in developing extraordinary properties obtainable only when employing the more expensive elements.

Considering the unusual properties determined in steel castings from the extreme other end of the composition scale, and omitting, for lack of space, detailed discussion of the commonly known alloy steels that contain chromium, nickel, molybdenum and vanadium, in percentages that are familiar to those who regularly purchase well-known grades of alloy steels, wrought or cast, it is in order to mention specifically, as representing material now being produced in many steel foundries to

Furnace for specially heat treating small castings.

increasing extent, the higher alloy steels often called "complex," and occasionally designated broadly as ferrous metals rather than as steels. Castings of such metals are now demanded for many applications where corrosion, oxidation at high temperature and other very severe agencies quickly shorten the life of steels of the carbon and simple alloy grades.

The manufacture of any such metal (as the "stainless" variety, "eighteen-eight," and other grades, including that frequently containing 35% nickel and 15% chromium) is successful only when experience is acquired along specialized lines. In the foundry, the behaviors of these metals differ from those observed in casting carbon steel, or the simpler alloy steels. Melting equipment needs to be specially adapted for the most satisfactory manufacture of some of these metals. In certain varieties there must be maintained through the most skillful furnace practices possible to establish, very narrow ranges in chemical composition. Special precautions must be taken in pouring, in shaking out and in cleaning. Unusual sand mixtures for molding are often found best to employ. Some defects that are not significant in the case of carbon steel castings, are very hazardous in certain high alloy steels. Despite the relatively great cost incurred in the manufacture of castings from many of these complex grades of metal, there are numerous uses where the longer life of the product more than justifies its selection.



Recently designed twin-chamber electric heat treating furnaces—one for heating castings, the other for slowly cooling them.

The Influence of Heat Treatment in Obtaining Varied Properties

Engineers generally realize that certain desired properties in alloy steels may be obtained only by employing carefully selected, closely regulated heat treatments. Consumers as a class know that each of several heat treatments given an alloy steel will develop properties differing greatly from those produced by another treatment. The great extent to which differences in physical properties are thus obtainable may be appreciated by reference to a few test results.

It has been announced to the trade by one reputable producer, that a grade of alloy steel regularly being put into castings is peculiarly susceptible to the tempering treatment, after being normalized at a temperature of 1650° F. When the drawing temperature ranges from 400° to 1200° F., the representative yield point varies from 180,000 to 100,000 lbs./in.^{2}, and the ultimate strength varies from 195,000 to 115,000 lbs./in.^{2} Percentages of elongation and reduction of area run from 10 to 21%, and from 30 to 50%, respectively. A Brinell hardness of 440 results from a draw at 400° F., while one of 255 is obtained when the metal is drawn at 1200° F.

It is clearly apparent that this steel (which contains, in addition to the five ordinary elements, several more expensive ones) is adapted to each of many extraordinary uses, quite different from each other. Here we have a good illustration of the manner in which one grade of alloy steel for castings may be variously utilized according to the nature of the heat treatment given the material.

Delayed Formulation of A. S. T. M. Specifications

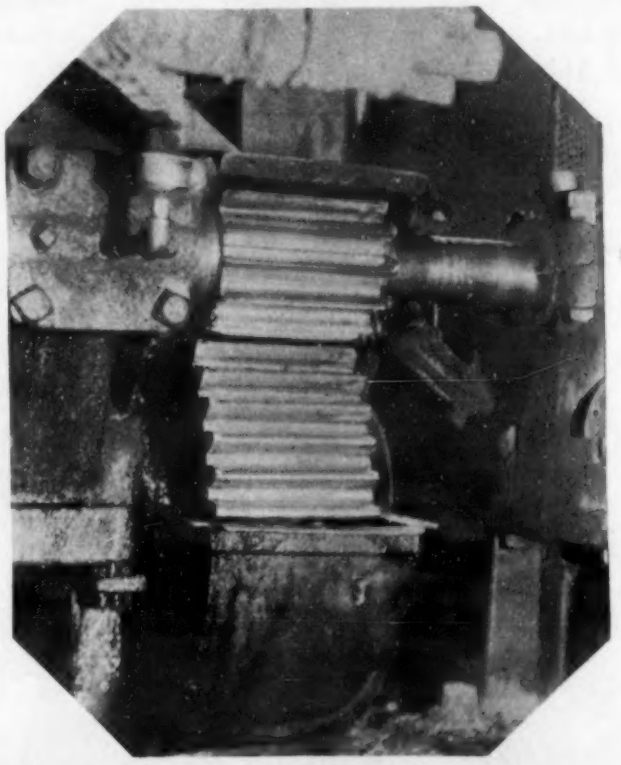
There are two phases of the cast alloy steel situation which are not now generally understood. One of these relates to delay that has resulted in the preparation of specifications promulgated by the American Society for Testing Materials for this product. Thus far, the Society has not adopted tentatively or as a standard, a specification for any grade of alloy steel castings excepting those of the austenitic manganese variety. Nevertheless, for several years the Society has sought sufficient data on physical properties to justify the formulation of purchase requirements. The principal reason for the considerable length of time consumed in formulating specifications lies in the relatively large number of plants now engaged in alloy steel casting manufacture, which were not producers of this material a few years ago. Foundries do not acquire broad experience quickly. Combinations of physical properties believed by experienced producers to be suitable for specification purposes, are accepted only with important reservations

by manufacturers who are passing through an apprenticeship. Whereas ten years ago there were very few steel foundries that regularly produced alloy steel castings exclusive of Hadfield's manganese steel, probably to-day the majority of the 300 or more steel casting plants in this country occasionally make one or more grades of alloy steels, while a fairly large number of these plants make several grades every month. In a few steel foundries, for several years, the greater portions of the outputs have consisted of alloy steel castings, exclusive of austenitic manganese steel.

Special Technique Needed for Special Steels

The successful production of alloy steels for castings often involves the application of principles in shop technique which are totally different from those properly governing the manufacture of wrought steels of the same chemical compositions. Wherever steel castings of any kind are made, shrinkage exists as a major problem, requiring practical experience for solution.

The degree of contraction in castings made from any grade of steel is governed, to a very large extent, by the design; and to considerable extent, by the pouring temperature, which latter should also be regulated by the design, in so far as thicknesses of section are concerned. For these reasons, one who makes jobbing or miscellaneous castings and who undertakes to produce castings of widely differing designs from a grade of steel with which the shop men are unfamiliar, may not only deliver an unsatisfactory product, but suffer heavy losses himself.



Chrome-nickel pinion which lasted a year under extraordinarily severe conditions. It took the place of a carbon steel pinion which required replacement about every two months.

This factor of shrinkage or contraction, if not properly provided for in foundry practice, may cause serious defects during the initial stages of manufacture, in cavities or in hot cracks, or both. The contraction phenomenon is of much greater significance in the production of several grades of alloy steel castings than when carbon steel castings constitute the entire output.

After the pouring and solidification of an alloy steel casting, which may subsequently be found free from shrink holes or shrinkage cracks, the part as cast, attached to gate and risers, may be extremely sensitive to temperature changes. That is largely dependent on the nature of the chemical composition. This susceptibility may be demonstrated forcibly and disastrously during certain manufacturing operations, such as shaking castings out of the flasks too hot, burning heads off by means of the gas torch applied too closely to certain members of "temperamental" tendencies, and grinding surfaces of heavy sections, at high speeds. There are grades of alloy steels used for castings which are so sensitive to these temperature changes that exceptional care must be exercised to avoid producing what are called "cold cracks," as distinguished from cracks due to red-shortness. The latter are occasioned by the inadequate resistance of the plastic or partially frozen metal when it endeavors to shrink according to the laws of nature, in a mold that materially retards natural contraction. Such ruptures as occur under the circumstances just mentioned are called "hot cracks," while other fissures resulting from unskillful grinding, burning, etc., are termed "cold cracks," being formed after the metal has cooled, following the pouring operation. Nevertheless, these so-called cold cracks are, in fact, frequently due to heat. They are readily distinguishable when the casting is torn open for explorative purposes, by bright fractures; while shrinkage or hot cracks (which are frequently wide enough to permit observation of the sides of the crevices) show the dark color caused by oxidation while red hot.

The explanations that have been offered may indicate that the responsiveness to heat application (which, to their great potential advantage is characteristic of many alloy steels adaptable for castings) represents one significant factor among several that constitute hazards when operations are performed inexpertly for the production of the material discussed in this article. These conditions are not always realized by those who purchase alloy steel castings.

Occasionally, buyers of this product indicate their belief that the extra expense incurred in producing alloy steel castings is regulated almost exclusively by the additional costs for the special raw materials put into the furnace. The consumer cannot be expected to have a clear idea of the expensive precautions resulting from experience, which must be observed, excepting as the producer takes occasion to explain the nature of conditions that must be met.

Of late there has been considerable matter published, stressing the importance of design for the production of satisfactory steel castings. It may be appreciated from what has been explained in this article that the factor of design, while very influential in the case of a carbon steel casting, is of tremendous significance in respect to many grades of alloy steels; that the two essential factors of intelligent designing and skillful foundry practice are of equivalent importance in the successful manufacture of castings from each of many grades of alloy steel.

Steel casting manufacture consists of a peculiar combination of art and science. It presents a most promising field for useful investigation. It becomes an absorbingly interesting field when the effort is made to develop technique for the satisfactory production of a large variety of alloy steels for castings. Fortunately for all concerned, there now prevails in the steel casting industry, a widely manifested spirit of exhaustive research in this and other respects, which may be confidently depended on to produce results of great value to those who design and use industrial equipment.

Oil as a Carburizing Medium

BY A. J. LINDBERG*

THE method of carburizing steel by the introduction of oil into a heated retort is not new. Attempts have been made in the past which indicated the simplicity, convenience and speed of this carburizing method, but until recently equipment had not been satisfactorily developed and the correct proportioning of the oil was not perfected. The present equipment and method have been in commercial operation about one year.

The author does not wish to be placed in the light of championing this method over the older methods, as his interest in oil carburizing is only from the standpoint of the user. The success of this method, as with all new methods, will be decided not by discussions in technical meetings, or technical literature, but by the satisfaction of the user of the process and the consumers of the products of that process.

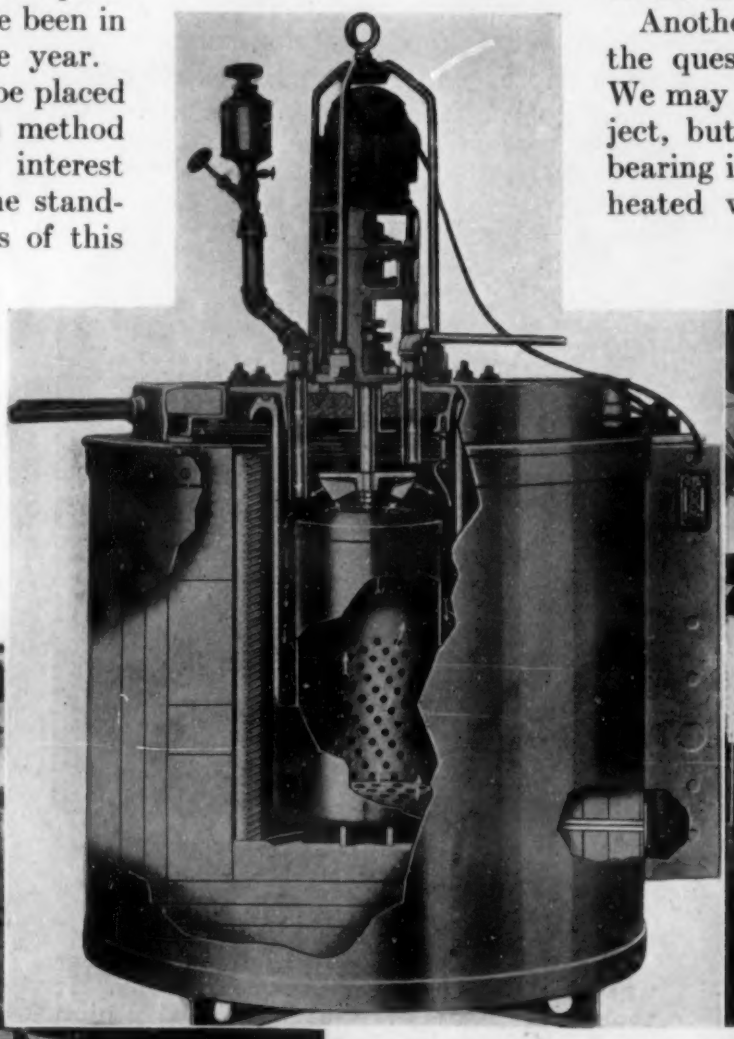


Fig. 1

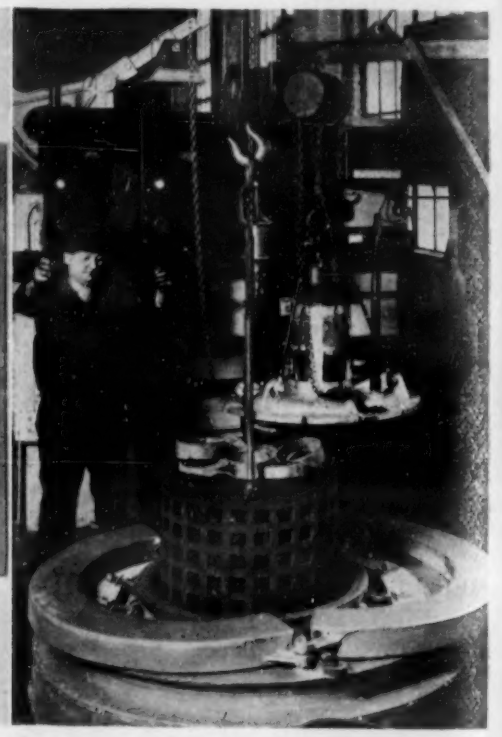


Fig. 3

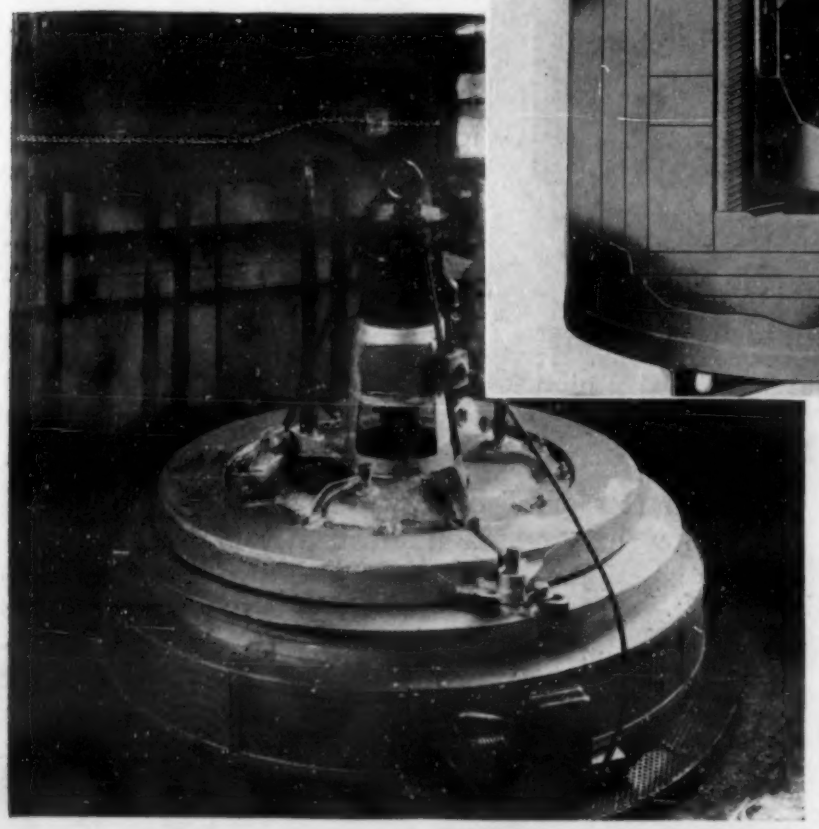


Fig. 2

The points to be covered are:

A brief description of the apparatus and its operation.

Methods of loading the charge.

The effects of time and temperature on case depths.

Control of carbon content.

The uniformity of case depths and carbon content throughout the charge.

The question of operating costs has purposely been omitted as of no importance metallurgically, except that any process must be economical within reason, before it can be of interest in practical heat treating. A careful check of these costs, even with our rather high electric rate, seems to indicate that the economics of the method are quite satisfactory.

Another subject carefully avoided is the question of electricity versus fuels. We may have our own ideas on this subject, but do not believe they have any bearing in this case. The retort could be heated with gas instead of electricity. A retort using gas as a carburizing medium can in turn be heated with electricity.

As a matter of fact the term "Gas Carburizing" might just as well be applied to this process, for the carburizing medium is gas which is generated in the retort as soon as the oil drops into the heated zone. The main point of difference, however, is that the oil is compounded to yield a gas most suitable for this use, while it is very apparent that city gas is not manufactured with its suitability for carburizing as the main object. Uniformity of the resultant gas from a definite carburizing oil is possible to a much greater extent than with city gas which may be a variable mixture of coal gas, oil gas and natural gas.

For the purpose of this paper, therefore, the author considers this method as "Gas Carburizing" and in the comparative data uses the usual box carburizing with solid compounds as a comparison. In the measurement of case depths, there being no standard as a guide, the total case is given as described in the A. S. S. T. Handbook from which is quoted as follows:

* Lindberg Steel Treating Co., Chicago.

"When the carburized steel is subsequently heat treated, a certain percentage of the case is high enough in carbon to permit hardening, thus fulfilling the purpose of carburizing. This useful portion of the case we shall designate as the 'effective case.'"

As for the mechanical side of the process, there are some differences which can be best shown by illustrations.

Fig. 1 shows a cut-away view of the furnace. This is the heating chamber with its elements which are divided into separate control zones, two in the small furnace and three in the large furnace. These zones are each independently controlled by a magnetic switch and automatic control pyrometer. Each zone of elements, therefore, releases just the proper amount of heat to hold the temperature of the retort adjacent to them at the correct temperature.

CARBURIZING is a venerable metallurgical process which, despite the inroads of nitriding, will always find a place in the production of metallurgical materials for engineering use. There are plenty of signs that the process will be improved and cheapened.

A new wrinkle is described in this article. It is especially interesting that the same equipment is found serviceable both for carburizing and nitriding, the longer nitriding process being carried on over Sunday, on the principle of "They work while you sleep."

Some users are inclined to think that the interposition of a carburizing heat between nitriding heats helps to avoid inefficient nitriding due to reaction between the ammonia and the container, keeping the container in better condition. If this be true, still wider use of the same equipment for both purposes is likely to come about.

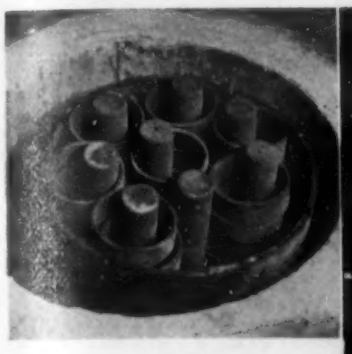


Fig. 4

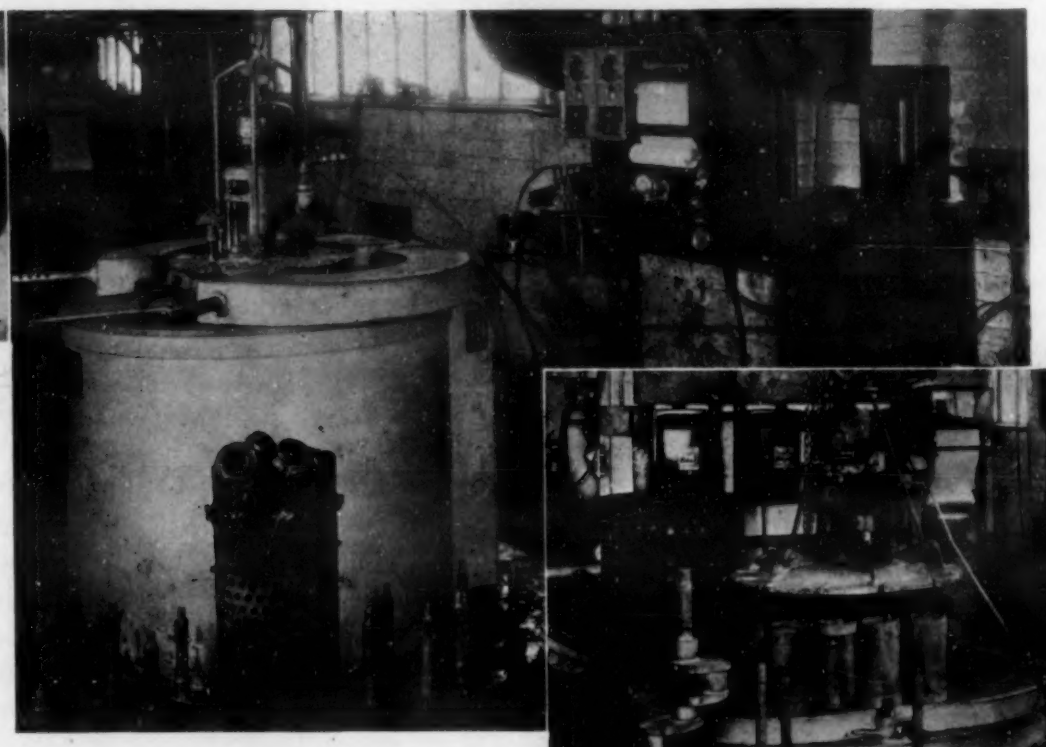


Fig. 5 ⟶

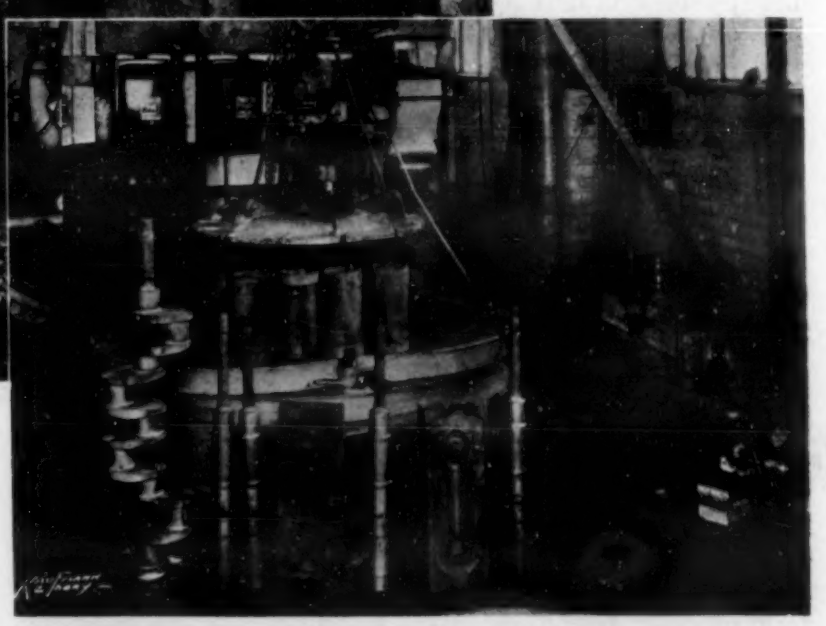


Fig. 6

The retort has an insulated cover which is bolted on tightly and sealed with an asbestos gasket. A motor is mounted on top of the cover and an alloy fan in the top of the retort. This fan is of the centrifugal type which sucks the gas up in the center and discharges it horizontally.

The carburizing oil is placed in a standard pressure lubricating cup and dripped into the fan discharge which throws it against the sides of the retort where it gasifies. The gas is carried through the charge and discharged through this exit pipe where it is burned. The amount of oil necessary can be regulated after a little experience by the size and color of this flame. The proper flame is a greenish gold color, an excess of oil resulting in a yellow tip and a smoky flame.

The work is charged into the basket and may be piled in haphazardly without affecting the case, except that flat machined surfaces must be separated by screenings and care should be taken not to place too great a weight upon the bottom of a load, which might result in distortion. In such a case the charge can be divided into two or more baskets, or supported on racks or fixtures.

The cycle of operation is as follows:

The work is loaded into the basket or fixture outside the furnace. It is then placed in the retort and the cover bolted on.

The furnace is then brought to the carburizing temperature and held for a sufficient time to be sure that the entire load is heated throughout. The oil is not turned on until this time to be sure that all parts of the load and the heavy as well as the light sections begin to absorb carbon at the same time and at the same rate.

After carburizing for the length of time necessary for the desired case, the oil drip is shut off and the furnace held at temperature an hour or two to allow the hyper-eutectoid case to diffuse. If the work is to be direct-quenched and if a lower quenching temperature is desired, the furnace can be cooled during this diffusion period.

The charge is then removed by quenching direct for core refinement or by removing the basket and placing in a pit for slow cooling, or if an absolutely clean surface is desired, the entire retort is removed and a second retort used with the next charge.

Fig. 2 shows the larger furnace which has a loading space inside the basket 24″ in diameter and 42″ deep. As much as 2000 pounds net has been charged in this furnace although average charges would be approximately 1500 pounds.

Fig. 3 shows a charge being removed. This happens

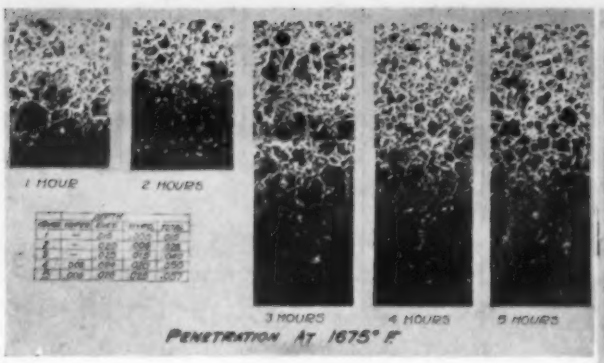


Fig. 7

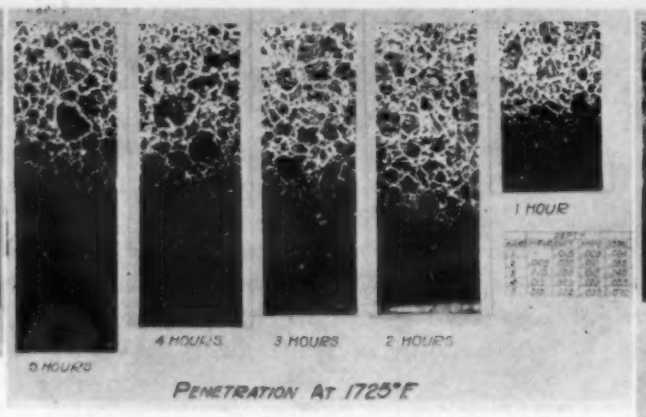


Fig. 8

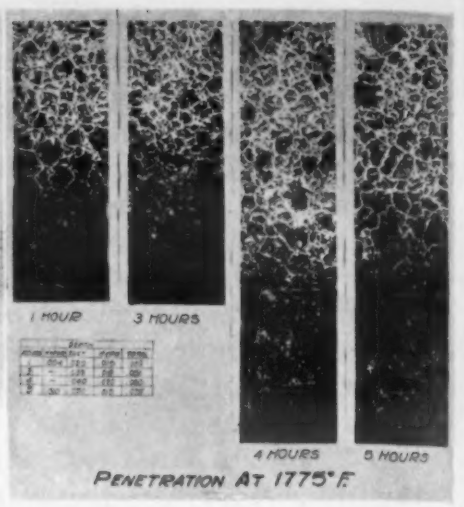


Fig. 9

to be large ball races which load rather lightly. This charge weighed only about 800 pounds due to the large amount of open space inside the rings.

Fig. 4 shows a charge in the cooling pit. It consists of rings similar to Fig. 3. Several very large round bars have been loaded in the same heat which brought the net weight up to over 2000 pounds. The elimination of distortion by loading the round bars vertically was important because such pieces would, of course, be very difficult to straighten.

Fig. 5 shows a smaller furnace which has a loading space 10″ in diameter by 20″ deep, and will hold a charge of 100 to 300 pounds. This size is very convenient in a shop where a great many small orders, each requiring a different treatment, are received. Five to eight heats a day are obtained from this furnace with very little attention on the part of the operators. On the panel are mounted the controlling and recording pyrometers, relays, a kilowatt-hour meter and an excess temperature cut-out. The magnetic switches are mounted on the side.

Fig. 6 shows a nitriding heat too large for the regular nitriding furnace. With the increase in the use of nitralloy it is often found necessary to run a nitriding heat in this furnace, particularly over week-ends.

Fig. 7 shows five samples of S. A. E. 3120 steel carburized at 1675° F. for one, two, three, four and five hours. The table shows the amount of the various zones in each sample.

Figs. 8 and 9 show a similar test on the same steel at 1725° and 1775° F.

Figs. 10, 11 and 12 show, respectively, ten samples of S. A. E. 3120 steel carburized at 1675° F., the first one for one hour, the second for two hours, the last one for ten hours, with cases ranging from 0.023 to 0.085 on the ten hour heat; a similar test at 1725° F. with cases ranging from 0.028 to 0.090; and a similar test at 1775° F., and running from 0.030 to 0.098. The furnace was held at temperature for ten hours and a test bar removed each hour. The samples show a rather sharp line of demarcation between the case and the core, inasmuch as in such a test it is impossible to diffuse each sample. The parts were quenched directly in oil from the carburizing temperature, and reheated to 1450° F., and quenched in water.

The method of operating these tests indicates the possibility of obtaining different depths of case in the same heat by opening the retort and removing the portion of the charge requiring the lighter case. During these tests the cover was removed at the end of each hour, and some carburizing speed may have been lost.

Fig. 13 shows the results of these three tests compared with the speed of box carburizing. These curves are very useful in the shop, for from them one can easily determine the time required to give a case of a certain depth at a certain temperature, e. g., an 0.080 case at 1775° F., requires seven hours. Some corrections must be made for the type of steel, surface condition, etc.

It will be noticed that the box carburizing line flattens out after a few hours' run, because the strength of the carburizing compound becomes less and less as it is held at heat. In the case of the other method, the curve flattens somewhat because the deeper the case the slower the carburizing; but here we have fresh gases being fed into the furnace throughout the entire heat.

This is not the entire story; however, the time shown on the chart is time at temperature only. Heating through boxes and compound is much slower than heating an open charge exposed immediately to a hot retort and with the heat driven through the charge with the fan agitation. Total time in a box furnace for $^1/_{16}$″ might easily be sixteen hours against eight hours in the retort furnace.

Fig. 14 shows two samples tightly wired together during carburizing and touching as they did in the furnace. The microscopic examination showed no effect on the case as a result of the contact.

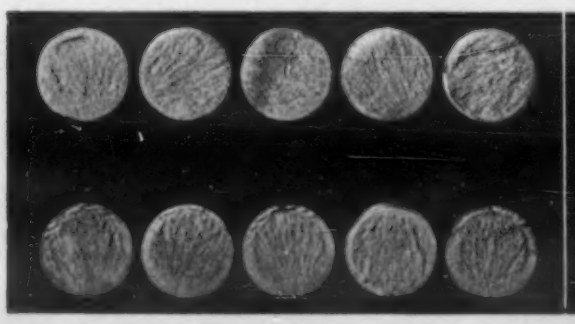


Fig. 10

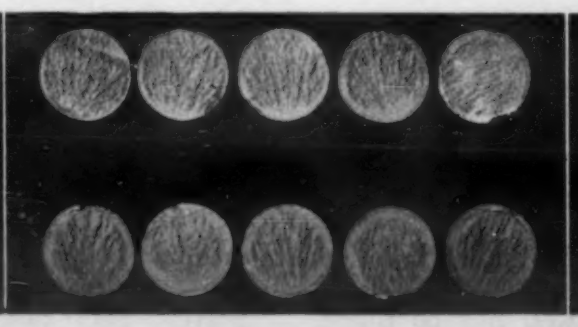


Fig. 11

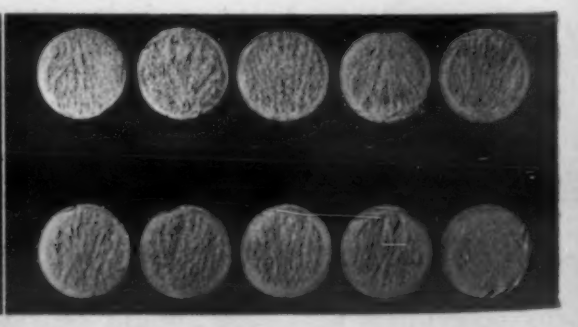


Fig. 12

Samples from the same heats show very uniform results. By cutting off the oil and continuing the heating one can bring about diffusion of carbon and thus the process is susceptible of considerable control.

The control over atmospheric conditions is applicable in other work than carburizing. For example, a sample of tungsten oil hardening steel, which decarburizes very readily except under ideal atmospheric conditions, was held at 1550° F. for two hours in the retort with a few drops of oil introduced. This is an excessively long soak, and ordinarily would have given a heavily decarburized surface. In spite of the long time at temperature, no decarburization was indicated by the microscope.

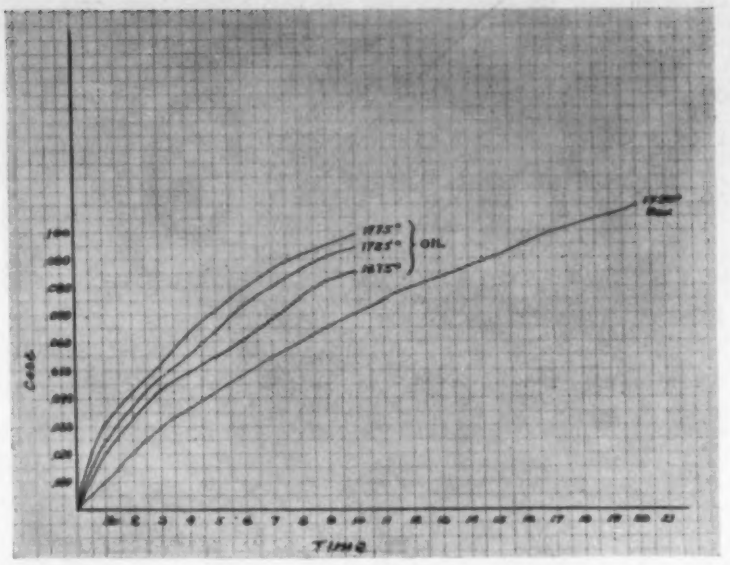


Fig. 13

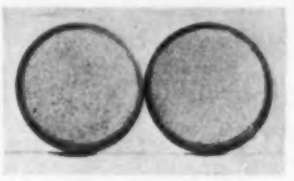


Fig. 14

One of the questions on this process which was particularly interesting was the effect on the uniformity of the case in a densely packed charge of small pieces, so about 1300 pins, $^5/_8$" in diameter and from three to four inches long, were packed into the basket of the small furnace. These pieces were shoveled into the basket haphazardly and represented the worst condition one would expect to encounter.

This charge was carburized for six hours at 1775° F., and diffused for two hours. The uniformity was highly satisfactory.

The short time this equipment has been in operation has not given time to make a complete study of its characteristics. An interesting phase is the effect of the shorter time at heat on the grain size of the core as compared to that obtained in box carburizing.

No study has been made of the effect of pressures in the retort. The tests run up to this time have been practically at atmospheric pressures. It is believed, however, that the little experience obtained indicates that this process will find an important place for itself in the Heat Treating Art.

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READERS' COMMENTS

EDITOR, METALS & ALLOYS:

We note with interest your article in January number of METALS & ALLOYS regarding the application of wrought iron where fatigue and corrosion resistance are desirable, and your comment on the lack of corrosion-fatigue tests on wrought iron. We have recently completed tests of that nature in our laboratory.

The Canadian railroads have been using mild nickel steels for staybolt materials for over 10 years. Wrought Iron is entirely out of the picture in Canada and also in England, where steel staybolts are used with steel fire boxes and copper with copper fire boxes.

Mistakes were certainly made in application of steel materials for staybolts in this country in the early days. For example—cold drawn steel was applied on five locomotives on a large railroad about 15 years ago, and these bolts broke so fast, the entire five locomotives were hauled out of service and staybolts removed.

Of course *steel* as a material for staybolts got a bad reputation on this failure, when the fact of the matter was, the cold drawing was responsible for the failure of the staybolts. Later experience has shown that staybolts must have a high Izod value, along with a fairly high yield point in order to prevent breakage in service.

The present specification on staybolts written by the Canadian Pacific railroad requires the minimum of 80 ft.-lb. Izod on hot rolled steel or steel ready for acceptance.

This specification almost precludes the application of anything but a low carbon analysis containing a minimum of $1^1/_2$% nickel.

A staybolt in service is subjected to water corrosion and to reversed bending stresses. Our method of testing was chosen to approach service conditions.

A section of the bar material to be tested is threaded and screwed into a plate of standard $^5/_8$" thick wrapper sheet stock. As shown in Fig. 1, the bolt is headed up as if it were being applied in a boiler and the regular tell-tale hole is drilled in the center. This method tests not only the staybolt but also the plate and the joint between the bolt and plate.

It is unique in comparison with other laboratory methods, in that it involves the testing of both the staybolt and the wrapper sheet of the boiler material, and the efficiency of the joint between the two parts. The stresses are complete cycles of reversal and under water conditions almost the same as in boiler service.

When running corrosion fatigue tests, a stream of water at 150° F. is flowed over the threaded section of the bolt.

The nominal fiber stress on the critical section of the staybolt, which is at the junction of bolt and plate, can be adjusted to any desired stress by the proper amount of weights on the rod, and can be calculated from the usual rotating beam formula. There is, of course, stress concentration at the junction.

The length from the face of the plate to the center of bushing where load is applied is $11^1/_2$ inches.

A load was applied to produce a nominal fiber stress of 18,000 lbs. at the junction of bolt and plate. The water was held around 150° F. The speed was 1150 r. p. m. This gives 1,650,000 reversals of stress in a 24-hour day. The life of the tests is given in days to failure. There is a wider spread in results on threaded sections than on polished smooth sections as are used in the other type fatigue machines.

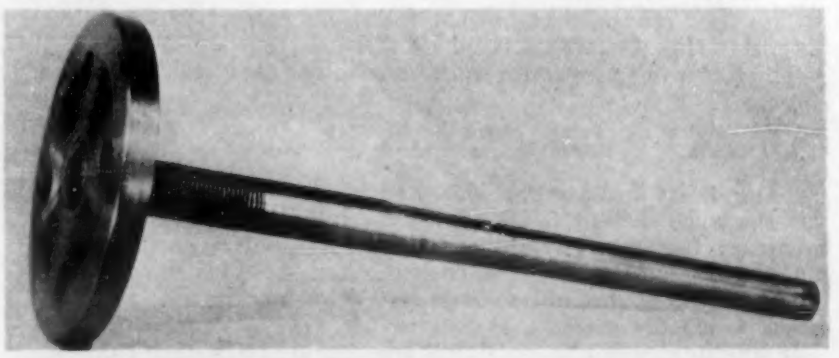


Fig. 1 Assembled test. Staybolt and wrapper sheet plate. Threaded end is fastened in plate and headed up and drilled. Plate is then faced off on back and fastened on special head in lathe. Bolt is then centered on other end and turned to true center. Bolt is standard 1" × No. 12 thread — $^7/_8$" round at outer end. Tapered from end of thread for 6" on length. Taper $^1/_4$" per foot.

Six brands of staybolt iron bought in the open market and samples of copper molybdenum iron and low carbon nickel iron taken from warehouse stock were used in these tests. The two latter materials were also run in the heat treated condition. The type composition of the Cu-Mo iron and the Ni iron and the heat-treatment used, are given below.

Type	C	Mn	S	P	Si	Cu	Mo	Ni
Cu-Mo Iron	0.05	0.30	0.03	0.02	0.01	0.55	0.15	....
Ni Iron	0.04	0.14	0.03	0.02	0.002	....	....	2.06

Heat treatment used; water quenched from 1630° F., drawn 2 hrs. at 450° F

The range of life as shown by several tests from each bar is as follows:

Highly polished sections under these conditions of testing

Life in days. Corrosion fatigue test—Rotating Beam. 1" Rd. bars, threaded #12 U. S. S. Standard thread. Running under water at 150° F. speed 1150 r. p. m. 1,650,000 reversal of stress per 24-hour day. Life of tests given in days and hours. Wrought Iron tests marked A-B-C-D-E-F. Cu-Mo Iron and Nickel Iron in "As Rolled" and "Treated" conditions marked T, N, TT, NT.

Test No.	A Days	A Hrs.	B Days	B Hrs.	C Days	C Hrs.	D Days	D Hrs.	E Days	E Hrs.	F Days	F Hrs.	T Days	T Hrs.	N Days	N Hrs.	TT Days	TT Hrs.	NT Days	NT Hrs.
1	4	6x	5	13x	19	3	13	3	15	9	7	3x	21	19	18	3	47	9	43	7
2	7	12	18	2	14	7	9	4	8	6	2	15x	32	7	15	7	36	11	49	1
3	6	14x	3	7x	9	6	17	21	21	4	19	21	26	14	29	4	59	3*	60	2*
4	14	3	9	4	17	18	16	7	16	19	12	4	19	7	19	3	72	10*	38	12
5	8	7	6	1	8	6	11	3	12	6	7	18	13	22	12	9				
Total	40	18	43	3	68	16	67	14	73	20	49	12	113	21	94	2	215	9	190	22
Average	8	3	8	15	13	18	13	12	14	18	9	21	22	18	23	81	53	9	47	12

x Tests stripped threads and pulled out of plate
* Tests removed—not broken

The physical properties and life under repeated stress at 18,000 lbs./in.² are shown in the following tables:

Material	Yield Point lbs./in.²	Tensile Strength lbs./in.²	Elong. 8", %	Reduction, %	Izod ft.-lbs.	Corrosion Fatigue Life Average 5 Tests	
Wrought Iron A	34,000	50,200	29	57.0	48	8 days	3 hours
Wrought Iron B	39,300	49,700	29	52.1	42	8 days	15 hours
Wrought Iron C	31,700	48,800	31	51.3	43	13 days	18 hours
Wrought Iron D	36,000	51,700	29	46.0	51	13 days	12 hours
Wrought Iron E	34,300	49,900	32	50.7	53	14 days	18 hours
Wrought Iron F	32,900	48,300	30.5	51.3	46	9 days	21 hours
Cu-Mo Iron	48,900	53,000	28.2	70.1	81	22 days	18 hours
Ni Iron	36,700	51,000	30.3	71.2	86	18 days	23 hours
Cu-Mo Iron Treated	49,600	62,400	21.5	72.4	91	53 days	9 hours
Ni Iron Treated	48,300	60,900	22.3	70.6	102	47 days	12 hours

would give more uniform results, but staybolts in service are threaded and the results in service are not uniform either, some bolts breaking long before others in the same row.

We found it very difficult to get the wrought iron bolts to break off unless they were machined to fit very tight in the threads.

When fitted in the ordinary manner the wrought iron bolts all tended to strip threads and pull out of the plate in a short time. This is due no doubt to the weakness of threads on account of slag inclusions. This bears out the data given the writer by several boilermakers that wrought iron bolts are more often replaced on account of stripped threads, rather than by breaking.

We also found that the wrought iron bolts did not last as long after a crack had started as did the Cu, Mo or Ni iron bolts. The surfaces of the fractured ends of wrought iron bolts were rough with little flattening or smoothing of the surface. The area of final rupture was around 40% on the wrought iron tests. The Cu-Mo iron and nickel iron seemed to hold on until the surface of fractures was smoothed down and final rupture rarely showed over 20% of the area.

The heat treated bolts showed more than double the life under the same conditions than the "as rolled" bolts and 3 to 10 times the life of the wrought iron bolts.

Bolts with Brinell much over 130 tended to cause failure in the plate rather than the bolt. The Brinell on standard wrapper sheet stock runs around 116 to 134, according to carbon content and finishing temperatures. Some tests on a steel staybolt stock from an outside source were run.

The steel staybolt was of the following analysis: C 0.12, Mn 0.41, S 0.045, P 0.032, Si 0.18.

The following properties were found on tests:

Yield Point	Tensile Strength	Elong. 8"	Reduction Area	Izod
47,300 lbs./in.²	62,800 lbs./in.²	28%	62%	17–19 ft./lbs.

These bolts had around 45,000 to 50,000 yield point but Izod values were low (15–20 ft.-lbs.). They showed crystalline breaks on fracture tests and only lasted 2 to 3 days on the testing machine. One broke in less than ten hours. This shows that a high yield point should be accompanied by good impact values to give satisfactory service.

It was interesting to note that when some tests were run with water temperature considerably above the boiling point, the water evaporated on the test sheets, depositing scale as in boiler operation. The scale was allowed to build up to 1/8" in thickness. We found that under scaling conditions the fatigue limits of the material were very nearly the same as running without water or in air. Lowering the temperature of the water to a point below the boiling point to prevent deposit of scale, caused a reduction of approximately 5,000 lbs. We believe this to be the factor of difference between fatigue limits of these materials working in air as opposed to working under water such as comes from the Canton City mains. Our water is high in magnesium sulphate and also contains some carbonates.

Conclusions

Cu-Mo iron and Ni iron in the hot rolled condition with yield point around 40,000 lbs. showed much better life than wrought iron bolts. Heat treated bolts showed best of all. Bolts with high yield point but low shock resistance were poorest of all.

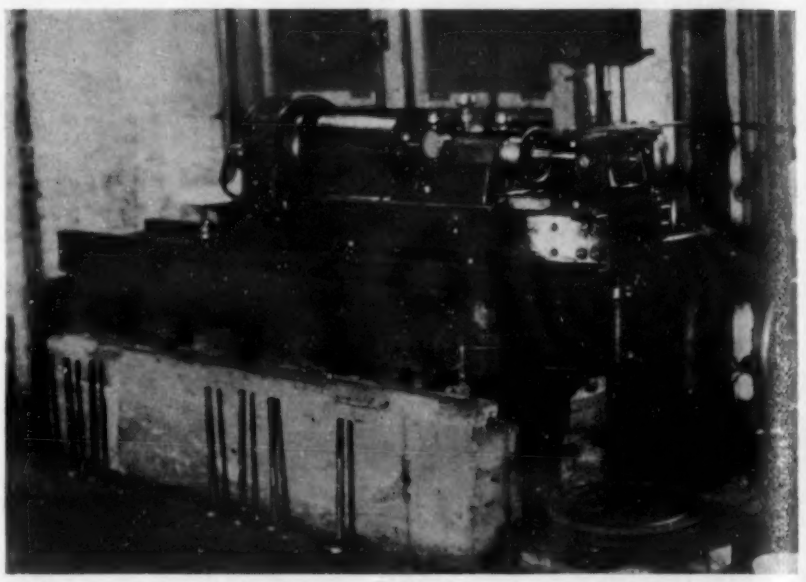


Fig. 2. Cantilever Staybolt test in fatigue testing machine. Assembled specimen is bolted into head stock of testing machine, outer end passes through bushing which runs in ball bearings. This bearing is in a yoke which is free to move in a vertical direction and has about 1/8" clearance on sides. The weight is supported on a coil spring in the pipe section and this acts as a vibration dampner. The indicator shows tne number of revolutions and failure of the bolt lets the yoke down and stops machine automatically.

The elongation on the best life bolts was fully 10% below the A. S. M. E. or A. R. A. requirements, yet three locomotives in hard switching service in a hard water district have been equipped with a full set of heat treated Cu-Mo iron bolts. They have all made nearly 100,000 miles apiece in service up to April 1931, and only one bolt has been removed from these engines in that period.

Material with a low yield point will show good elongations, that with a high yield point will show less elongation. Neither of these factors is directly related to the Izod test or shock resistance. Furthermore, a bolt with a low elastic limit become very quickly over-stressed and ages and becomes very brittle, showing a crystalline fracture.

To obtain the maximum service in a locomotive firebox the following properties, obtained by heat treating, are recommended for staybolts:

Yield Point	Ultimate	Elongation	Reduction
45,000–50,000	58,000–63,000	18–23%	65–75%
Izod		Brinell	
75–100 ft.-lbs.		116–134	

H. L. Miller

Metallurgical Department
Republic Steel Corporation
Central-Alloy Division

(Readers' Comments Continued on Page 119)

AGE HARDENING of COPPER-TITANIUM ALLOYS

BY EARLE E. SCHUMACHER* AND W. C. ELLIS*

IN A general investigation of copper–alloy systems, it has been observed that certain copper–titanium alloys are age hardening. The three alloys which were studied contained, respectively, 0.67, 0.93 and 2.03% of titanium by analysis. The series was prepared from cathode sheet copper and a pure titanium obtained by the reduction of the chloride with sodium. The first two alloys were prepared by fusion under hydrogen; the third, by melting in vacuum. The age hardening phenomenon is demonstrated by the results given in Table 1.

Table 1.—The Effect of Heat Treatment on the Hardness of Copper-Titanium Alloys

Alloy No.	% Titanium	Rockwell Hardness B-1/16–100 kg. Load: Quenched in H_2O after One-Half Hour at 875° C.	Rockwell Hardness B-1/16–100 kg. Load: Aged 4 Hours 400° C.
1	0.67	2	15
2	0.93	17	36
3	2.03	37	82

The most pronounced hardness change was obtained with the alloy containing 2.03% of titanium. The detailed changes resulting from aging this alloy at 3 different temperatures over a total period of ten hours are shown in Fig. 1. Maximum hardness was attained in approximately two hours at 500° C.

SINCE the pioneer thinking of Merica, followed closely by elaboration by Jeffries and Archer here, and by others abroad, so that the mechanism of the precipitation-hardening of alloys with the Duralumin type of solubility curve became understood, many alloys capable of age hardening have come into the service of mankind. Many systems in which it was not suspected have been found, on sufficiently careful examination, to show it.

Here are data on another interesting alloy of this type, from the Bell Telephone Laboratories.

The change in resistivity resulting from the aging of quenched alloys is shown in Table 2. There was a decrease in resistivity in all cases, but the maximum change was obtained with the alloy containing 2.03% of titanium.

Table 2.—Effect of Heat Treatment on Electrical Resistivity of Copper-Titanium Alloys Drawn to 0.100 in. Diam. Wires

Alloy No.	% Titanium	Electrical Resistivity—Microhm cm. at 20° C.: Quenched in H_2O After 1 Hour at 875° C.	Electrical Resistivity—Microhm cm. at 20° C.: Aged 1 Hour 500° C.
1	0.67	5.95	5.84
2	0.93	7.32	7.02
3	2.03	19.80	10.50

The increase in hardness together with the decrease in resistivity obtained by aging quenched alloys shows conclusively that this is an age hardening system of the general type, in which the hardening results from the precipitation of a phase from a supersaturated solid solution.

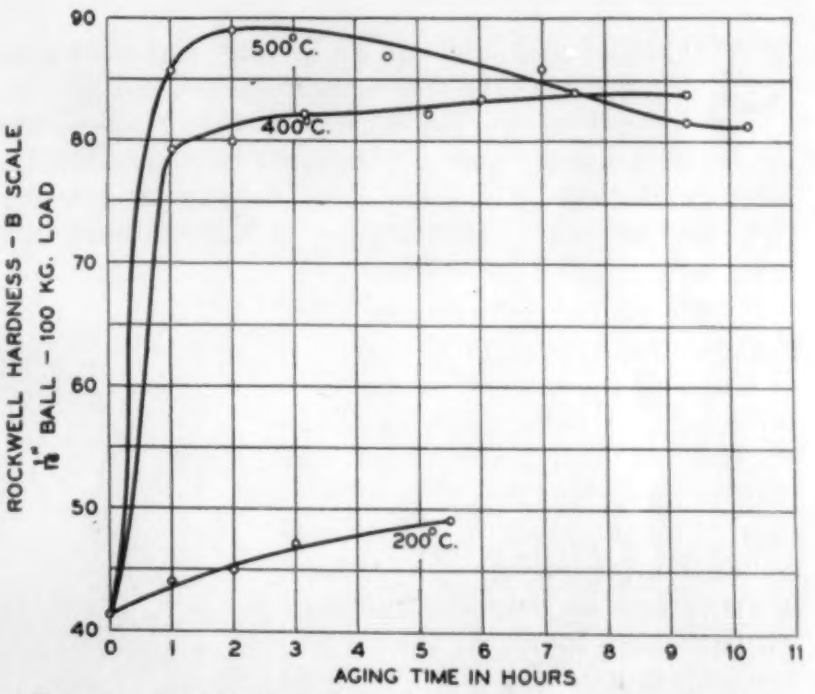


Fig. 1. Effect of aging temperature on the hardness of a copper titanium alloy containing 2.03%Ti.

No data are presented at this time to establish the nature of the dispersed constituent or the equilibrium diagram of the system copper–titanium.

The tensile strength of the copper-titanium alloy containing 2.03% of titanium was determined in the heat treated condition. A tensile strength of 92,000 lbs./in.^{2} associated with an elongation of 10% over a two-inch gage length was obtained.

The same age hardening characteristics were obtained in copper-titanium alloys prepared from impure grades of titanium. Two different titanium materials were used. One was a titanium produced by aluminum reduction which contained approximately 90% of titanium; the other was a copper-titanium addition alloy containing approximately 8% of titanium. This product, it is understood, was also obtained by aluminum reduction. Titanium when added to the alpha solid solutions of copper also produces age-hardening materials.

Since this article was submitted for publication, a paper describing the properties of copper-titanium alloys appearing in the January 1931 issue of *Zeitschrift für Metallkunde* by Dr. W. Kroll has become available to readers in this country. This paper shows that the system copper–titanium is age hardening, and in addition submits evidence establishing the equilibrium relations of the copper-rich alloys.

* Bell Telephone Laboratories.

Causes and TOOL STEEL

BY W. H.

STEEL for tools is a key material, as we found out in war-time. Without tool steels, modern industry would be helpless, for valuable as are the newer tungsten carbide and tantalum carbide tools, these will be put to special service rather than generally to replace, for years to come, at least, our present tool steels.

These little pieces of steel have an important duty to perform, and their failure causes delay, irritation and expense far greater than the cost of the material in them.

By proper coöperation between the maker and user of tool steel, many failures can be avoided.

USERS of tool steel can be broadly classified into two groups—the tool manufacturers and the industrial users. For the first tool steel is regarded as a raw material and is purchased in comparatively large quantities. The other class includes those using it as an accessory to their regular production work and is by far the more numerous.

Each class has its problems which are sometimes common to both. It is much to the interest of tool steel producers to have these problems worked out and many times they play an important part in their solution. Our intention in this discussion is to bring out how the producer is concerned to help the customer with questions involving the use and application and also the quality of the product.

The tool manufacturer is primarily interested in the steel that will give best performance on a given class of tools. Having standardized on the compositions or types and worked out the heat treatments, such other points are given consideration as hardness or structure that will lend itself best to the various machining operations, the use of forgings rather than hot rolled bar stock, or the finish or surface condition that may call for the use of cold-drawn material. Many tool makers order tool steel to their own specifications covering such points as analysis, size tolerance, hardness, structure, limit of surface decarbonization and freedom from surface or internal defects. In most cases these specifications can be met without undue difficulty on the part of the mill. However, the tendency is toward higher standards, calling for more elaborate inspection systems.

A service failure. Heat-checking of a tungsten shock-resisting tool steel die for hot-pressing brass.

The business of most tool makers is on a sufficiently large scale so that they are organized for the inspection of the incoming raw material or tool steel, as well as for the proper investigation of tool failures, or other complaints involving their own product. They may also carry on research work on tests of various tool steel grades, or on the development of new tools or lines of product. Such concerns have a very intimate knowledge of the tool steels regularly used and the principal consideration of the mill or producer is to furnish material that runs uniform and conforms to specifications.

Industrial users, in contrast to tool manufacturers, have a great and increasing number of applications for tool steel and more varied problems. Smaller quantities are purchased at a time and in a great variety of sizes and grades.

The mills have their regular tool steel brands designed to take care of all ordinary applications of the customer. The great variety of modern industrial requirements makes it necessary to have more than one brand in some cases coming under each of the classifications. Naturally the mills aim to limit their regular brands to as few as will adequately take care of the trade, but there is a constant tendency to increase these. This is not strange because developments in the field or research on the mills' part may call for a change of analysis or introduction of a new type.

One of the user's tool steel problems that is of major importance is how to select the right steels for his different jobs. Industrial users in particular very often depend on their source of supply for these recommendations. Through contacts with other customers, the mills are in a position to render valuable assistance along this line. Sometimes a mill is called on to make a survey of all the requirements of a customer, making recommendations of brands, along with suggestions as to heat treatment. This is done bearing in mind that it is to the interest of the user to carry as few grades of tool steel as possible, at the same time properly taking care of all applications.

The needs of a customer may change with change of manufacturing methods, or the production of a new line of products, and here again the mill should be on the

* Chief Metallurgist, Ludlum Steel Co.

Avoidance of FAILURES

WILLS*

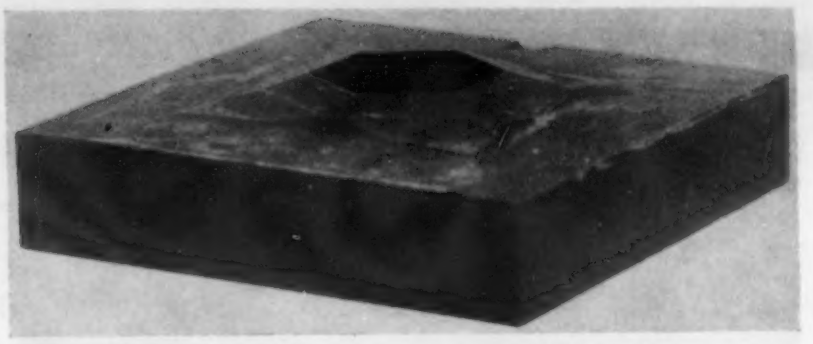
job to render service. For instance, parts formerly made on automatic screw machines may be made by the cold heading process.

Cold heading is also cutting in on hot work operations among the bolt manufacturers. Threading may be done by rolling instead of cutting or vice versa. Castings may be replaced by forgings made on semi-automatic hot work machines. Stampings often take the place of castings or forgings. Coin press operations eliminate certain machine operations, and as a subdivision under this may be mentioned the hobbing of embossing or forming dies that formerly meant long die sinking or routing tool work.

In the non-ferrous metal industries, extrusion press work has to some extent replaced rolling mills with resultant increased use of hot work tool steels. More forging and hot pressing of copper and brass is done now than ever before. The die casting of low melting point alloys has displaced some machining and assembly work and brought about a demand for the die casting steels of special composition which go into the molds.

In addition to the changes of methods that mean new requirements of tool steel, the user welcomes something better for his present operation. The mill has this in mind constantly and is at work on such questions either through the making and testing of new analyses, or through investigations of present standard brands.

Other problems of the customer may involve tool design, tool steel forging, machining, heat treating and grinding. The mill can help with these in two ways. First, it can give the benefit of its experience in the case of forging and heat treating; and second, where tool failures are involved, it is anxious to learn whether the steel or the customer's methods are at fault. Matters can then be corrected accordingly. As previously mentioned many users are not equipped to investigate tool failures themselves, and consequently it is up to the mill to take care of this work for them. In fact those that do such work themselves,



An example of good design. Cold pressed nut trimmer die of high carbon chromium steel. This deep-hardening steel has a low impact value, but by use of generous wall thickness it stands up to its work. Made from flat instead of round bar stock, it has a better structure at the cutting edge.

Service failure of a carbon tool steel cold header die that was too hard. Its Rockwell cone hardness was 62 to 63, when it should have been drawn back to 58 to 60.

Grinding cracks on part of a high speed steel shaper cutter. The machinist tried to take too heavy a cut in grinding and spoiled the cutter.

are often glad to have the mill work with them to verify their findings.

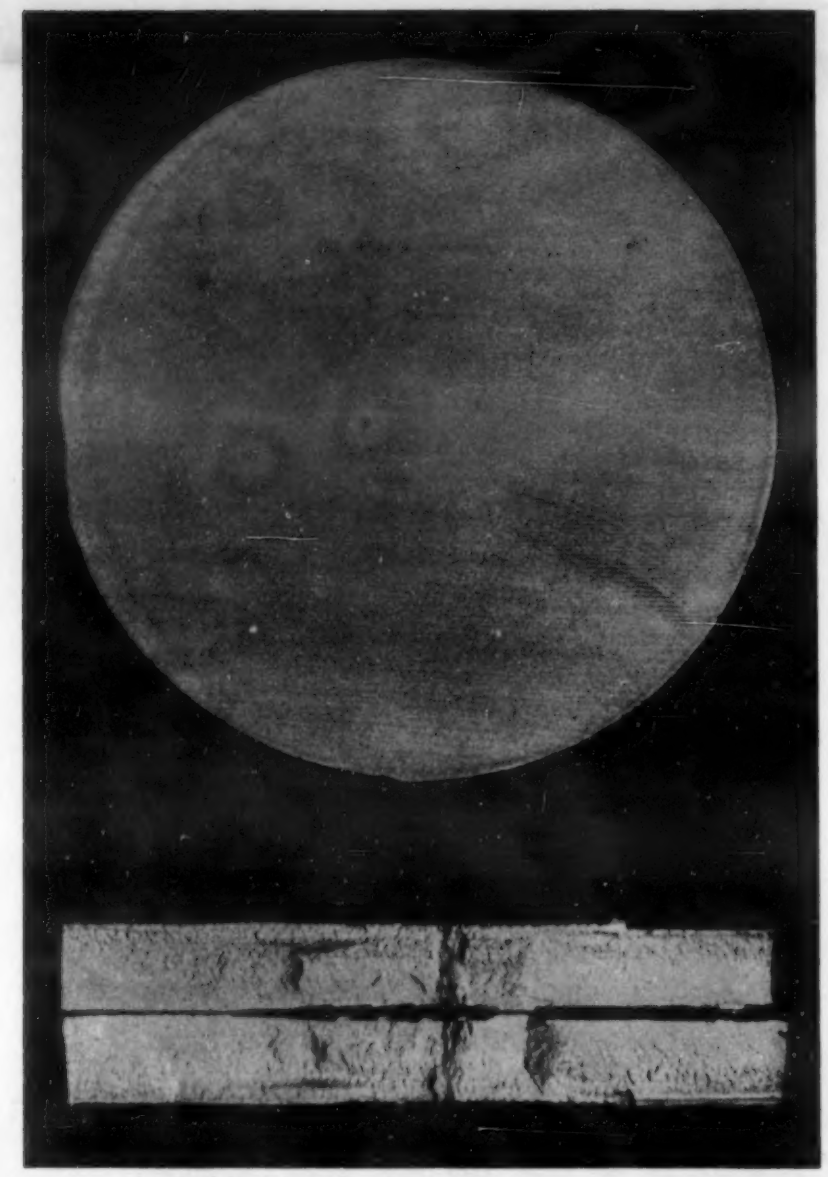
Heat treatment is the source of more tool failures by far than any of the above sources, and among industrial users in particular this is not apt to be realized. The basis for this statement is that over a period of years about 60% of all complaints found to be the customer's fault are laid to heat treatment. Tool manufacturers in general with their large investment in tool steel and their tool quality ever in mind give both equipment and personnel careful attention. The main factors that cause trouble are:

1. Rapid heating resulting in nonuniformity of the parts at temperature when quenched.
2. Overheating, and to a lesser extent underheating.
3. Improper furnace atmospheric conditions resulting in decarbonization or soft spots.
4. Improper drawing.

In some plants accurate records of heat treatments given are kept and regular schedules of time and temperature worked out for each class and size of tool. This, of course, applies in a large measure to tool manufacturers and not to the average tool room. In the latter case, the human element is especially prominent for it takes more than a good furnace and an accurate pyrometer to turn out perfect tools.

These are some of the things that may go wrong so far as the customer is concerned. Of course, the steel itself may be at fault, but the mills strive to avoid such causes of complaint. Records over a period of years show that of all complaints approximately 40% may be laid to the customer and 60% to the mill. Those that are the mill's fault may be classified as follows with the approximate percentage:

1. Internal Defects.....30%
2. Inspectors' Errors.....35%
3. Wrong Analysis or Grade. 5%
4. Annealing or Heat Treating 8%



Deep-etching and fracture tests both show the defective center of this 4″ round section of carbon tool steel.

The balance includes cases of sales errors, or where the responsibility cannot be definitely fixed.

Internal defects may include some things that are apt to get by careful inspection, and the mill must be ever on the alert to deal with their prevention or correction. They often can be traced to the ingot and usually constitute a melting department problem. This refers in particular to secondary pipe, inclusions, metallic and non-metallic, gas cavities which show up as internal seams in the finished bar stock and carbide segregation. Such defects are apt not to occur uniformly throughout a heat and may at times present a baffling problem. Closer control in the melting operation is a live subject, especially the study of ways of checking up on quality before the ingots are hammered or rolled.

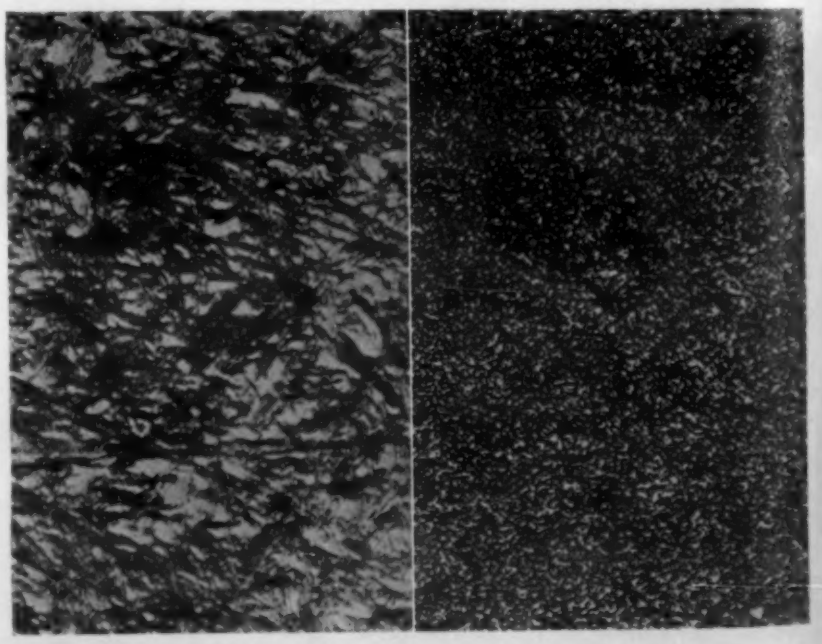
Poor structure and hammer burst are listed under the head of internal defects. The former applies to conditions arising from insufficient working from the original ingot, or improper heating in the hammering or rolling. The persistence of traces of ingot or cellular structure in finished bar stock is met with at times, mostly in the highly alloyed steels, such as high speed, or the high carbon chromium types. Hammer burst may be caused by working too cold, or from a weak center structure.

Under inspectors' errors we have the items that are looked into in the regular warehouse inspection, taking in surface condition, seams, pits, etc.—pipe, decarbonization, size, shape and straightness. Surface seams originate at times in the ingot and can largely be eliminated by proper billet inspection and grinding. With some grades they may occur as result of too rapid cooling after rolling, or too low a finishing temperature.

Surface decarbonization is brought about in the heating operations for hammering or rolling and annealing. Annealing is under quite close control and in many instances the cycle is held to automatically. Also standard practice is to protect the material in tubes or boxes. On the other hand, with the hammer shop or rolling mill heating furnaces, even though often equipped with pyrometers, much depends on the human element when it comes to holding proper time, temperature and furnace atmosphere. While highly oxidizing atmospheric conditions will cause excessive bark, there is more to it than this alone. Time elements enter in strongly, particularly in annealing, and the investigation of the various factors involved is quite a study in itself. Some types of steel are more subject to decarbonization than others. Most customers are reasonable in their requirements or specifications covering depth of decarbonization, the tool manufacturers being the most exacting in this respect.

Complaints coming under wrong analysis or grade are few in number, but they are generally serious because often the customer has put considerable labor on the steel before anything is found out. Mixups happen once in a while not only at the mill, but also in the customer's tool room. The mill with its numerous grades to keep separate in ingot and billet stock as well as in form of finished bars must use a systematic marking system throughout. The average customer has only a few grades to keep separate and it is a simple matter to mark tools and dies so they can be traced to the original shipment.

Under annealing come some of the complaints on machinability which often result from insufficient annealing. Sometimes the steel is annealed too soft



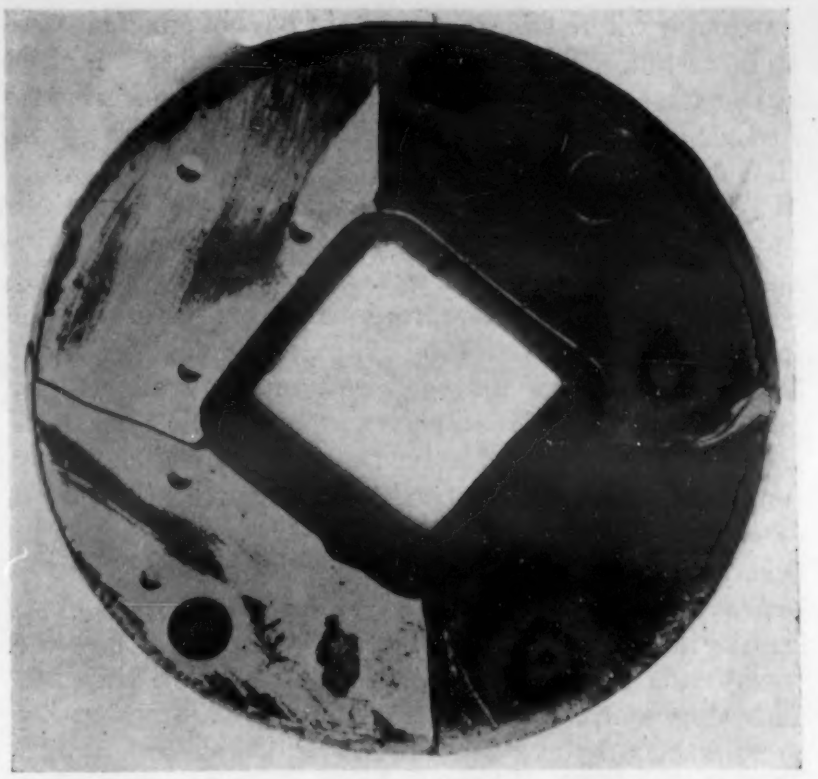
The microscope shows a cause of failure. At left, the structure of a manganese oil-hardening steel die, badly overheated in hardening, producing a brittle structure. This die broke in service. At right, the fine structure obtained by proper hardening, giving the best combination of hardness and toughness, as well as the desired "non-deforming" property. Both ×500.

resulting in tearing in certain milling operations, thereby producing a rough surface. On the other hand there are cases of machining difficulty where the steel has not been at fault, and a change of cutting compound, set up, or grinding of the tools has been the solution. In one instance a customer using large carbon tool steel rounds claimed they cut very hard on the hack saw. The steel showed a low Brinell hardness and a later investigation showed that the hack saw blades were extremely soft.

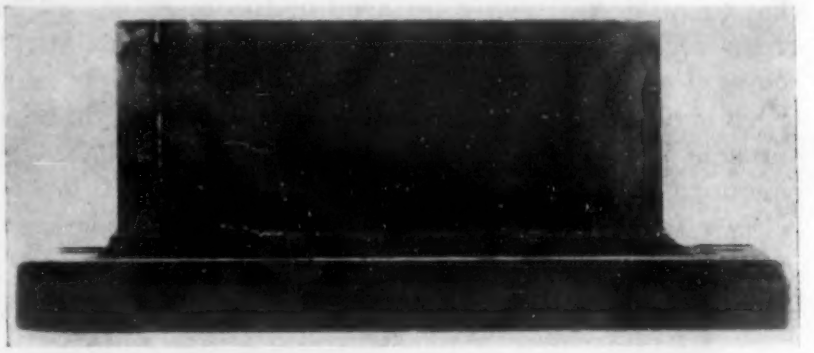
From the mill's standpoint the annealing of every order to produce ideal structural conditions is quite a problem. The average annealing furnace has a capacity of 5000 to 10,000 lbs. of bars and to run economically requires full charges. A variety of sections may go into a single heat and the time, and to some extent the temperature, is governed by the size stock that makes up the bulk of the charge. Development of the electric furnace and improvements in pyrometer equipment have been great helps toward good annealing.

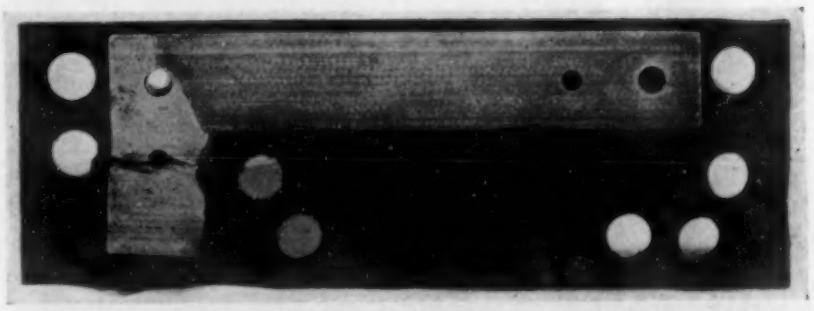
Present methods of mill inspection have advanced materially from those of the old days when surface inspection and examination of the topped or fractured ends of the bars for pipe, grain size, and bark was about the limit of what was done. Carbon was estimated by the appearance of the fracture. This is in marked contrast to what must be done to-day. Our industrial progress is reflected in much higher standards of quality. The mills are working continually toward better control of their operations, which is necessary, if rejections of the finished product are to be held to a minimum. Inspection of surface and fractured bar ends is now made the same as in the past. Numerous hardness tests are made to check up on the uniformity or completeness of the annealing. Unless otherwise ordered the mill works to regular Brinell hardness limits on the various grades. Sometimes a customer specifies a maximum Brinell only and again upper and lower hardness limits are given.

Laboratory tests are now quite common that were unheard of not many years ago. The science of metallography has progressed to such an extent that the microscope has become indispensable for checking up on structure, and micro examination is routine on many orders. This inspection is carried out on a representative number of samples which may be examined for inclusions, proportion of lamellar pearlite or spheroidized carbides, carbide segregation, or in the case of highly alloyed steels, carbide distribution. Some tool makers insist on very low decarbonization limits and it is necessary to check up on such orders microscopically. This applies generally to comparatively small sizes and to highly finished cold-drawn products. The examination of hardened fractures under a low power microscope has in some cases worked out better than looking at the polished cross section under a higher power for this purpose. This applies in

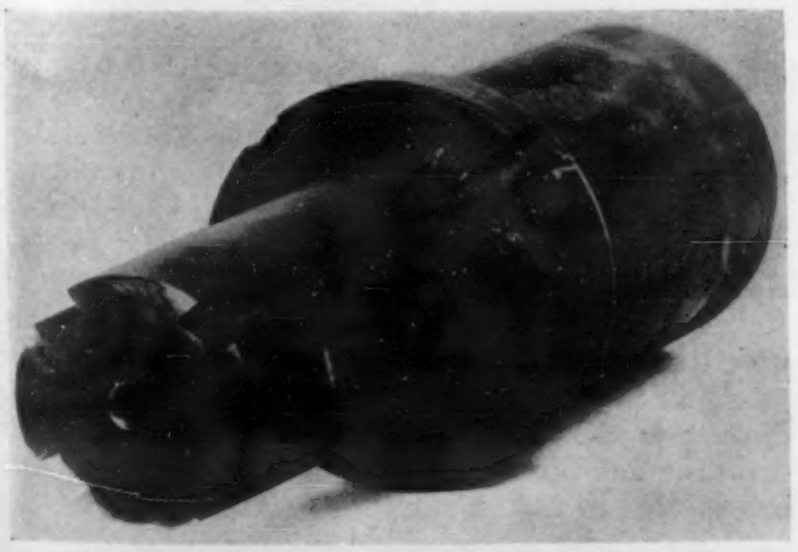


An example of poor design. A forged high speed steel extrusion die for brass, operating at 1400° F. under heavy pressure. The die was too small for the size extruded and could not dissipate the heat, hence it cracked at the corners.





This high carbon high chromium steel die cracked after hardening. It was heated 100° to 150° F. too high in hardening.



A punch made from 2 1/8" round high speed steel, and not drawn promptly to relieve hardening strains after quenching in oil. Large sections designed with sharp corners are liable to this type of failure. A less drastic quench, as into lead at 1100° F., then air, or air-blast cooling, helps in such cases.

particular where a large number of bars of small size are to be tested. The samples must be heated in a molten bath such as lead for hardening so as not to decarburize further and the method may be used with any grades that can be hardened in lead.

The deep etch test, though not new, has come into more prominence in recent years as a method of inspection for internal defects. It is generally carried out by immersing discs representing cross sections of the bars in a strong solution of hydrochloric acid for about 30 to 45 minutes or more. The temperature is usually 160° to 200° F. The attack of the acid on the metal is, of course, in proportion to the time in the bath and the temperature and concentration of the acid. Thickness of the discs and number handled at a time should be taken into account in determining the proper length of time. Other factors that have their effect are inherent strains in the metal that may be from rolling, shearing (near ends of the bars) and also from cold drawing. Finishing temperature after rolling or hammering has some effect on the attack of the acid. Various grades of steel are attacked differently—manganese oil hardening steel etching more readily than carbon or high speed steel. High speed, high carbon chromium, and other highly alloyed types whose structure is characterized by large carbides that are irregularly distributed show up unfavorably after a prolonged etch. This, of course, is due to pitting showing up around the large carbides. Deep etching will, of course, magnify such defects as segregation, inclusions, seams, and traces of pipe, but there is nothing to be gained by prolonging the time in the acid beyond what will show these up plainly. On account of the many variables involved and the intensifying effect of the etching, care and experience are required in the interpretation of results. In the case of minor defects or irregularity showing up, the decision to pass or reject should be backed up by a knowledge of the performance of the tools made from the steel being thus tested, and of the common types of failures. This method of testing is especially valuable for checking up on the center condition of bars going into dies where the center is subject to great stress or wear as for cold header dies, drawing or embossing dies. When one considers the insignificant cost of the steel as compared to labor on the average tool or die, the expense of this kind of inspection appears little. On the other hand, the application of this testing to hundreds of bars in the course of a month represents quite an item of cost and illustrates one phase of the mills' efforts to satisfy their customers.

The examination of hardened fractures is a useful test, particularly on high speed steel in the larger sections. It is to be preferred to deep etching with some grades and is a good way to check up when in doubt on the deep etch test.

The terms "normal" and "abnormal" as applied to carbon tool steels, relate to uniformity and depth of hardening. The carbon and carbon vanadium in carbon ranges below 1% tool steels may show some variation in this respect. There are some customers that want such steels deep hardened or showing a so-called normal condition. However, for ordinary applications, the slight differences that may exist have no harmful effects assuming proper heat treatment. Inspection for abnormality is carried out by carburizing a test piece for 3 or 4 hours at about 1800° F. and examining the case. Uniform grain size and continuous cementite grain boundaries are characteristic of normal steel. This is checked up by the examination of hardened fractures and surface for uniform hardness.

As a result of modern manufacturing and inspection methods, tool steel customers are getting better results than ever before from the tool steel they purchase. This follows from first, better heat treating equipment and methods; second, closer relations between producer and user and better understanding of tool steel problems, and finally, from greater efforts on the part of the mills to maintain high standards of quality.

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(**Editorial Comment Continued**)

The Light Metals in Italy

Metallurgical attention in Italy seems to be concentrated on the light metals. One can pick up a new issue of *La Metallurgia Italiana*, and be pretty sure to find one or more articles dealing with rather extensive research work on aluminum.

Besides taking the lion's share of the space in that journal, the light metals now have a new Italian journal, *Metalli Leggeri*, all to themselves. This is devoted to aluminum, magnesium and beryllium, though inclusion of the latter in the sub-title does seem to be rushing matters just a bit.

Several books, also, have recently been published in Italy that deal with light metals and alloys. In shese books and articles, it is stated, in almost the tame words, that Italy is poor in iron ore and coal but rich in bauxite and electric energy, so that aluminum is destined to become the "steel of Italy." So much emphasis is put on the value of a highly developed aluminum and magnesium industry from the point of view of national defense, that it seems very probable that the activity in these lines is urged on by the Government. The present aluminum production of Italy is small, and that of magnesium very small, but with the interest being shown, and the dissemination of so much information about and propaganda for, the use of the light metals, it would seem probable that a gradual increase in use and production might be expected in that country. H. W. G.

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Alexander L. Feild, has been appointed director of development and research of the Rustless Iron Corporation of America.

Dr. A. J. Phillips, formerly metallurgist with the Scovill Manufacturing Co., is now Superintendent of Research at the American Smelting & Refining Co., Maurer, N. J.

Effect of SURFACE DECARBURIZATION on FATIGUE Properties of STEEL

BY C. R. AUSTIN*

FOR some time it has been generally recognized that the endurance limit of ferrous materials as placed in service may vary considerably from the value obtained from the conventional tests carried out in a machine using polished cylindrical specimens.

Various experiments have been conducted to demonstrate the marked lowering of the fatigue limit by notching or scratching the surface of the test specimen. In 1912 Kommers[1] showed that if the fatigue specimen was tested in the rough-machined condition instead of being ground to size, a decrease of as much as 30% in the endurance limit was obtained. Later Moore and Kommers[2] demonstrated almost 20% decrease in a 0.5% carbon steel by rough grinding.

The deleterious effect of a brittle skin on a ductile metal as in case-carburization and electro-plating has also been given consideration.

It is in the researches on spring steel, however, where surface effects appear to have had the greatest recognition. Batson and Bradley[3] working at the National Physical Laboratory found that the very low limiting ranges of stress in laminated springs compared with that which the materials will stand in the form of turned and polished specimens is due to what they term a "skin effect." In a recent publication by these authors[4] further consideration of the "skin effect" is discussed, and it appears that the authors conclude that this "surface effect" was produced by hardening and tempering. G. M. Eaton[5] has frequently referred to this subject and considers surface decarburization a serious factor in lowering maximum working stresses.

Despite this generally acknowledged probable influence of surface decarburization on fatigue limit, it is difficult to cull definite experimental evidence from the literature to prove this contention or to indicate the magnitude of the effect. A somewhat analogous case has, however, received some experimental attention. The endurance limit of duralumin averages about 15,000 lbs./in.^{2} Pure "Alclad" aluminum probably runs about 5000 lbs./in.^{2} The endurance limit of "Alclad" duralumin is about 10,000 lbs./in.^{2} Thus the fatigue strength of duralumin is markedly decreased by the molecular contact with it of a thin coating of pure aluminum.

It was considered, therefore, that data, although limited, on the effect of surface decarburization on the endurance limit of a commercial steel should prove of interest.

The material examined was a 95,000 lbs. minimum tensile steel having the following composition:

Carbon	0.38 %
Manganese	1.51 %
Phosphorus	0.022%
Sulphur	0.034%
Silicon	0.26 %

To determine the true effect of surface decarburization on the endurance limit of a steel, it is clear that the most satisfactory method to adopt is to use two sets of samples of the steel which have been subjected to identical heat treatment, one set having a thinly decarburized case and the other set being free from any decarburization. This is the procedure adopted in the present work.

It appeared that the readiest means of obtaining limited controlled surface decarburization would be by heating the steel in a stream of hydrogen at an elevated temperature. Previous published work of the writer[6] indicated that the optimum conditions could best be obtained by several hours' treatment at about 700° C. This treatment tended to produce a peripheral layer of completely decarburized steel due to the slow rate of diffusion of the carbon from the core toward the periphery.

Accordingly, after some preliminary observations, the procedure was as follows:

1. One set of six specimens was machined to size and heated at 700° C. for 18 hours in a two-inch bore silica tube through which a stream of moist hydrogen was

IN service where repeated stress is involved, especially where the maximum stress is at the surface, the nature of the surface and the propensity of the underlying material to allow a crack to propagate or to stop its advance, are highly important, but too little understood, as was pointed out on page 115 of Vol. 1 of METALS & ALLOYS. Laboratory endurance tests, for which the natural surface of the specimen is removed and the new surface polished, often fail to reflect correctly the behavior of the material in service. The effect of even slight surface decarburization upon endurance limit is too little understood by heat-treaters, metallurgists and engineers. This article brings out important points that all of these should note.

* Section Engineer, Metallurgical Division, Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

[1] *Proceedings International Association for Testing Materials*, Article V4a, 1912, 15 pages.

[2] *University of Illinois, Engineering Experiment Station, Bulletin* 124, 1921, page 108.

[3] Researches on Springs. *Report of Scientific and Industrial Research*, Engineering Research Report, No. 13, Nov. 1928, 33 pages.

[4] *Institution of Mechanical Engineers*, London, Preprint, Feb. 1931, 16 pages.

[5] Stress Distribution and Hysteresis Losses in Springs. M. F. Sayre & A. Hoadley. *Transactions American Society Mechanical Engineers*, 1928, Progress Report No. 4, APM 51-24, pages 287-305; discussion by G. M. Eaton, page 304.

[6] Hydrogen Decarburization with Observation on Related Phenomena. *Journal Iron & Steel Institute*, Vol. 105, 1922, pages 93-155.

passed. The furnace was shut off and the specimens cooled in place in dry hydrogen to prevent tarnishing.

2. A second set of samples was machined a little oversize and similarly treated.

3. The first decarburized set was then annealed in hydrogen for 40 minutes at 760° C. Experimental arrangement was made so that the series could be immediately withdrawn to the cold end of the tube. This was the nearest approximation to the normalizing of this steel that could be readily devised. The hot steel could not be air normalized on account of oxidation and hence spoiling of the surface finish.

4. The second series of specimens was treated similarly.

5. In order to prepare for fatigue test, the decarburized series was given merely a final polish. This did not affect the dimensions of the test-piece.

6. The second series was turned down to size to remove the decarburized layer and each specimen was then polished.

The extent of decarburization was arbitrarily fixed at about one-hundredth of an inch. One specimen from each of the two series, D71–12 and D71–17, was selected for examination in order to ascertain that a correct amount of surface decarburization had been accomplished and that the microstructure and tensile properties were sufficiently comparable to insure that any difference in the value for the endurance limit obtained could be ascribed to surface decarburization. This examination consisted of metallographic analysis, Rockwell hardness and tensile tests.

Metallographic Analysis

Both of the above-mentioned specimens were cut near the center of the test-piece and the cross-section polished and examined under the microscope.

Fig. 1 is representative of the microstructure of the non-decarburized specimen and this structure persists to the extreme edge of the test-piece (see Fig. 3). Fig. 2 is representative of the general structure of the decarburized steel. From these photomicrographs it can be anticipated by previous work of the writer on these low manganese steels that very similar tensile properties would be obtained. The decarburization on the periphery of the test-piece is shown in Fig. 4. Figs. 5 and 6 illustrate the structure at the periphery of another decarburized sample on opposite sides of the section after the test-piece was broken by cyclic stresses.

Fig. 1. Specimen D71–17. Microsection showing general structure of the non-decarburized steel as put under fatigue test. Etched in 5% nitric acid in alcohol. ×100.

Fig. 2. Specimen D71–12. Microsection showing general structure of the surface decarburized steel as put under fatigue test. Etched in 5% nitric acid in alcohol. ×100.

Fig. 3. Specimen D71–17. Microsection showing complete lack of any peripheral decarburization of specimen shown in Fig. 1. Etched in 5% nitric acid in alcohol. ×100.

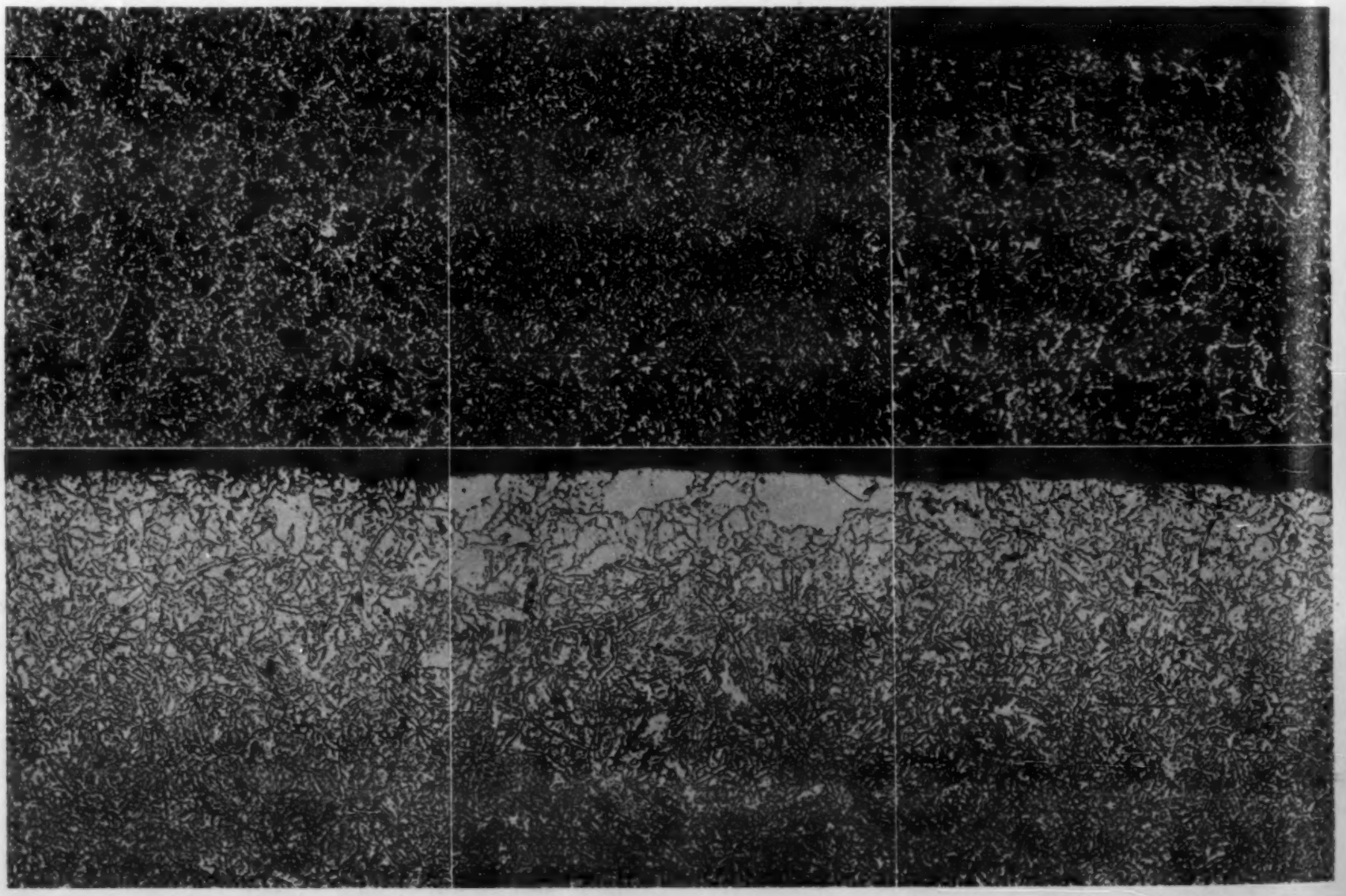

Fig. 4. Specimen D71–12. Microsection showing decarburization on the periphery of the test specimen shown in Fig. 2. Etched in 5% nitric acid in alcohol. ×100.

Fig. 5. Specimen D71–10. Microsection showing decarburized periphery of fatigue specimen which failed under 1,049,300 reversals at 40,000 lbs./in.² Etched in 5% nitric acid in alcohol. ×100.

Fig. 6. Specimen D71–10. Microsection as in Fig. 4 showing opposite side of specimen. The decarburization has not been quite symmetrical. Etched in 5% nitric acid in alcohol. ×100.

From these photomicrographs it is clear that only the desired limited carbon reduction has been effected.

Rockwell Hardness Tests

Rockwell hardness tests were made on the transverse section of the specimens used for microscopic analysis. An average value of 94B was obtained in each case.

Tensile Tests

Small 1 1/2-inch length tensile test-pieces were prepared from portions of the same two test specimens as above, having a 0.25 inch gage over 1/2-inch length, in order to confirm that the two series were similar in tensile properties. This test also indicated what fatigue value might be expected from the steel under the given heat treatment. The tests were naturally made on specimens free from any surface decarburization in either series. The tensile values obtained were as follows:

Non-decarburized series.	Specimen D-71-17.	110,200 lbs./in.²
Decarburized series.	Specimen D71-12.	111,600 lbs./in.²

This compares with the 112,000 lbs. tensile value for the "as rolled" and normalized steel obtained in routine physical testing of this material.

Fatigue Tests

The testing machine used was the R. R. Moore rotating beam type fatigue testing machine. The test specimens and method of carrying out the test are well known. The results are given in the following table.

1. Decarburized Series

Specimen No.	Stress in lbs./in.²	Number of Cycles
D71–8	46,000	290,500
D71–7	40,000	1,110,300
D71–10	40,000	1,049,300
D71–11	39,000	1,499,900
D71–9	38,000	7,530,500*

2. Non-decarburized Series

D71–14	48,000	1,267,400
D71–15	47,000	1,755,800
D71–16	47,000	10,000,000*
D71–13	46,000	7,546,000*
D71–18	Not tested	.....

* Did not fail.

Consideration of Results

The two series of fatigue test specimens were subjected to similar heat treatments in order that the physical characteristics would be the same. Metallographic examination, hardness testing and tensile tests demonstrated that structurally similar steels had been obtained except for the presence of a limited decarburized surface layer in one of the series.

All specimens in each of the two series were treated at the same time so that the experimental conditions were well defined.

It has been shown that the endurance limit was decreased from 47,000 lbs. to 38,000 lbs./in.² This represents a drop of some 20%. It was possible to obtain reliable endurance data with a limited number of specimens as the physical characteristics of the steel were well understood. The routine endurance limit was 46,000 lbs./in.² in the "as rolled" state, and 49,000 lbs./in.² as normalized.

It is believed that the results herein outlined represent the first experimental effort to demonstrate in a quantitative manner the effect of surface decarburization, per se, on the endurance limit of steels.

(Readers' Comments Continued from page 110)

EDITOR, METALS & ALLOYS:

Tour* has described experiments indicating that in the heat treatment of high-speed steel, proper control of the atmosphere in the furnace chamber allows the steel to be exposed to furnace temperature considerably beyond the usual time taken as the permissible limit, and yet not bring about grain growth.

Beside this retarding action upon grain growth, some users of our "certain-curtain" controlled atmosphere furnace report that by critical regulation of furnace atmosphere they are able to control distortion and dimensional change. While such changes are, of course, primarily due to the nature of the steel itself, it is obviously desirable to have control over any other factor that may play a part.

By use of manometers to show the gas-air ratio supplied to the combustion slot in our furnace, control of the atmosphere is effected. Some preliminary tests were made in treating a high-speed steel of the usual type analysis 0.70% C, 18% W, 4% Cr, 1% V, using specimens 1" long by 1/2" diameter. A constant gas pressure of 1/2" of water was used in all tests, and air pressure varying by steps of 1" from 1" of water pressure on test No. 1., to 10" on test No. 10. Gas samples from the furnace chamber of the high-speed furnace gave the results tabulated below:

Test No.	CO_2 %	O_2 %	CO %	Dimensional Changes[1] inches in 1/2 inch diam.[2]	inches in 1 inch length[3]
1	5.6	0	9.6	+.0001	−.0008
2	6.6	0	7.9	+.0006[4]	0
3	8.6	0	3.9	−.0001	−.0007
4	9.2	0	2.6	−.0001	−.0008
5	10.0	0	1.0	−.0005	−.0010
6	9.9	0.1	0.1	−.0017	−.0010
7	10.0	0.4	0	−.0020	−.0015
8	9.5	1.9	0	−.0017	−.0005
9	8.9	2.6	0	−.0015	−.0010
10	8.4	3.8	0	−.0010	−.0020

[1] Measured after pickling 20 min., and scratch-brushing.
[2] Average of measurements on both ends, agreeing within .0002".
[3] One test only.
[4] At preheat 10 min. instead of 7 min.

It will be noted that as soon as oxygen appears in the gases in the furnace chamber, there is an abrupt change in the diameter of the specimen; instead of the dimensional change being in the fourth decimal place, it jumps to the third. While the length changes do not follow the change in gas composition so closely, yet the average decrease in length for atmospheres without oxygen is 0.0007" while that for atmospheres with oxygen is 0.0012".

The specimens were preheated 7 min. at 1550° F. in a controlled atmosphere furnace, using the gas-air ratio of test No. 2 and presumably giving an atmosphere of similar composition. They were held at high heat, 2340° F., for 2 min.

The specimens had been notched, and were broken at the notch and Rockwell C hardness determined at the fractured surface and on the outer surface. All fractured surfaces showed 65 1/2 ± 1/2 and all outer surfaces 65 ± 1/2 with the exception of test No. 10, on which the hardness fell from 65 at the fracture to 63 on the outside.

The specimens were then drawn 1 hr. at 1050° F. in a Homo furnace when all fractures showed 64 or 64 1/2 with the exception of the No. 3 which was up to 65. The outer surfaces all showed 63 or 63 1/2 except Nos. 1 and 2 at 62 1/2 and No. 3 at 64, but had a very thin file-soft skin.

On grinding off about 0.001 to 0.002" all outer surfaces showed 64 1/2 ± 1/2 except No. 5 at 63 1/2.

Thus, there is no notable or consistent differences in hardness of the different specimens that would account for the difference in dimensional changes noted, and we are forced to the tentative conclusion that the dimensional changes are in some way related to the furnace atmosphere.

We hope later to supply data on further tests along this line.

J. E. HINES
C. I. HAYES, INC.

Providence, R. I.
August 5, 1931

* S. Tour. The Heat Treatment of Delicate Tools of High-Speed Steel. *Fuels and Furnaces*, Vol. 8, Sept. 1930, pages 1251–1258.

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Dr. H. W. Gillett, Director, Battelle Memorial Institute, Columbus, Ohio, and Editorial Director of METALS & ALLOYS, has been appointed a member of Committee E-9 on Correlation of Research for five years, to succeed Dr. G. K. Burgess, whose term expired with the recent annual meeting. Doctor Burgess has been a member of the committee since its organization in 1924 and has rendered inestimable service during his term of membership.

Heat Treatment of Plain & Alloy

BY F. B.

THE NATURE OF CAST IRON

WITHOUT a doubt, the most versatile of metallic materials is cast iron. Upon visual examination, the fracture of a particular casting of cast iron may appear white and brilliant and the material be hard, brittle, weak and unmachinable. The fracture of another casting may be dull and gray and the material be relatively soft, less brittle, strong and readily machinable. The fracture of still a third casting may show both of these types of structure side by side. This variation in structure is due, chiefly, to two elements other than iron present in plain cast iron and which are the most important in their effect upon the structure and properties of that material. These are carbon and silicon. Carbon can exist in complete chemical combination with iron, as iron carbide or cementite, or partly or entirely free as graphite. Silicon plays a dual role. Part dissolves in iron (called ferrite) and part in cementite (iron chemically combined with carbon). The presence of silicon in cementite renders that material unstable, causing it to have a tendency to partially decompose and liberate some carbon as graphite. That is, a gray cast iron will consist of a metallic material (essentially a silicon steel) the continuity of which is broken up by particles of graphite. That is the nature of cast iron, a steel-like body interspersed with either graphite or iron carbide or both.

THE STRUCTURE OF CAST IRON

When properly prepared and examined at suitable magnification through a microscope the details of the structure of cast iron can be readily observed.

In Fig. 2[4] is shown the structure of a white iron. In this material all carbon is chemically combined with iron. Two general types of structure are apparent. The massive plain areas are cementite. This material contains 6.67% carbon. The crinkly appearing areas are pearlite, each of which consists of alternate layers of ferrite and cementite. While the combined carbon in pearlite is small (about 0.80%) the structure consists of 88.0% iron and 12.0% cementite. The average total carbon, however, of an entire section of such a white iron is only 3.5%. Fig. 1[1] illustrates the changes which occur, during the process of cooling from the melt, in a thin section of such an iron containing no silicon or other impurities.

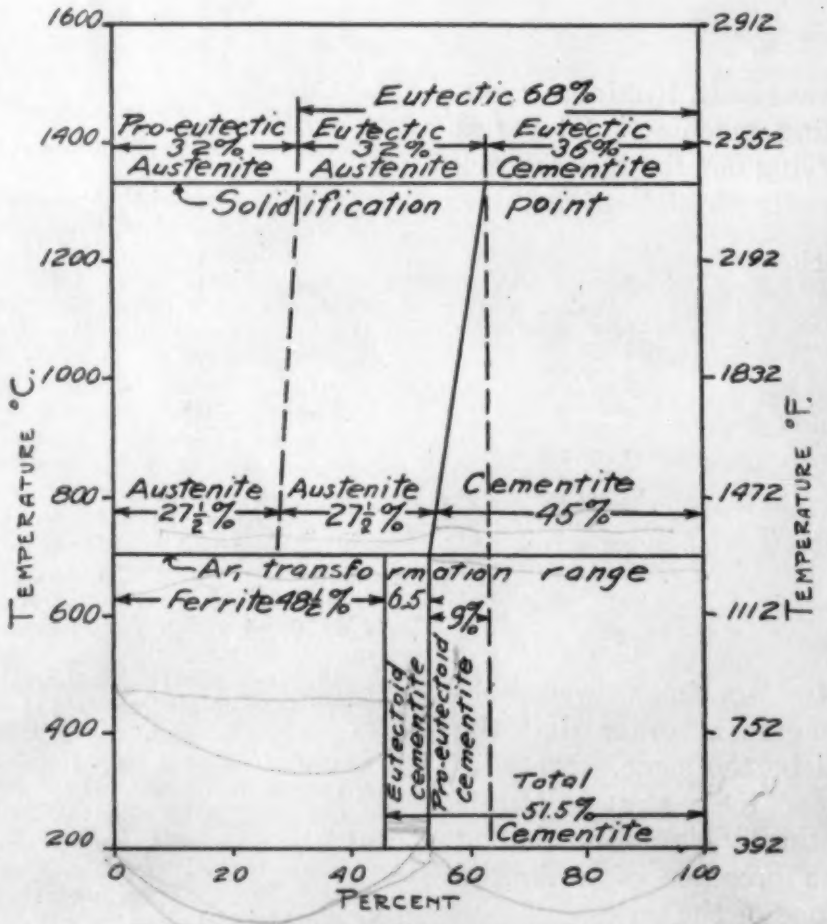

Fig. 1. Diagram illustrating the mechanism of solidification of Hypo-eutectic White Cast Iron (Whitfield).

This shows that the structure at room temperature consists of 45.0% cementite and 55.0% pearlite containing 6.5% cementite. The Brinell hardness number of this type of iron will average 450 to 500.

If the foregoing iron contained about 1.3% silicon, a different structure would result. Some silicon would have dissolved in the austenite and some in the cementite. Silicon causes cementite to become unstable and to separate into pearlite and graphite. The result of such an addition is illustrated in Fig. 3[4] which shows graphite flakes (black) and the characteristic lamellar or plate-like structure of pearlite. The combined carbon in this type of structure is approximately 0.80%. The Brinell hardness may vary between 180 and 220.

Now think of a cast iron containing about 2.25% silicon. As shown in Fig. 4[4] an altered type of structure is obtained. Besides the black streaks of graphite and half-tone areas of pearlite there is another lighter constituent visible. This is iron containing a small quantity of silicon and impurities in solution. The proportions of iron (ferrite) and pearlite can vary over a wide range, depending upon the exact chemical composition and past history of a particular casting. The combined carbon may vary from 0.05 to 0.75%. The Brinell hardness will vary accordingly between 125 and 175. The metallic portion of this type of iron is identical with that of a mild, or medium carbon steel or a low carbon tool steel.

Another type of structure is shown in Fig. 5.[4] This shows black flakes of graphite and practically carbon free individual grains of ferrite. The Brinell hardness of this type of iron is usually 120 to 125.

The structure of cast iron is also materially affected by the presence of alloying elements which by their particularly individual characteristics group themselves in two categories:

1. Carbide-forming—such as vanadium, cobalt, chromium, molybdenum and manganese. According to present knowledge such elements combine in nominal amounts with carbon and iron and tend to change structure from that shown in Fig. 4 to that shown in Fig. 2.
2. Graphitizing elements—such as nickel, aluminum, titanium, copper and tungsten. These elements cause cementite to decompose into graphite and pearlite and possibly some ferrite.

Some of the alloying elements, when added in small quantities to cast iron, act as scavengers (deoxidizers or degasifiers).

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Fundamentals of CAST IRON

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In appreciable quantities some manifest their effects by altering the metallic structures shown in Figs. 3 and 4 into new types. Consider the effect of nickel. Fig. 6[4] shows the effect of adding 3.5% nickel. This structure, which is called sorbite, is granular and unresolvable through the microscope even at extremely high magnifications. The Brinell hardness of this material may vary between 230 and 300. This structure is similar to that of some steels after certain specific heat treatments.

With the addition of approximately 5.0 to 11.0% nickel a still different type of structure is obtainable as shown in Fig. 7.[4] This is called martensite and resembles the structure of a file hard tool steel. The Brinell hardness, as cast, may vary from 300 to 425.

The increase in alloy content demonstrated up to this point has caused a progressive hardening with change in structure. Further increase in nickel (more than 11.0% or 12.0%) will produce not only another new type of structure (austenite as shown in Fig. 8[4]), but will cause an astounding decrease in hardness. The Brinell hardness of this type of structure is about 110 to 125. This is a structure similar to that of non-magnetic and corrosion-resistant steels.

It must be clear, then, that since the metallic structure of gray iron resembles that of steel in its various phases it should respond to heat treatment, at least to some extent, in a manner similar to that of a silicon steel with a corresponding structure.

THE EFFECT OF HEAT UPON THE STRUCTURE OF CAST IRON

The effect of heat upon the structure of cast iron is twofold:

1. The effect upon eutectic and pro-eutectic carbide (massive carbide shown in Fig. 2).
2. The effect upon the other types of structure (ferrite, pearlite, sorbite, etc.).

The effect of heat upon eutectic and pro-eutectic cementite depends upon:

1. Temperature.
2. Composition.
3. Time.

According to Sawamura[2] graphitizing elements, in general, lower the temperature at which eutectic cementite begins to break down (see Figs. 9 and 10). It is indicated in Fig. 11 that if more than one graphitizing element is present each may supplement or probably even accentuate the effect of the

Fig. 2. Microstructure of White Cast Iron. Mag. ×500. Etched.

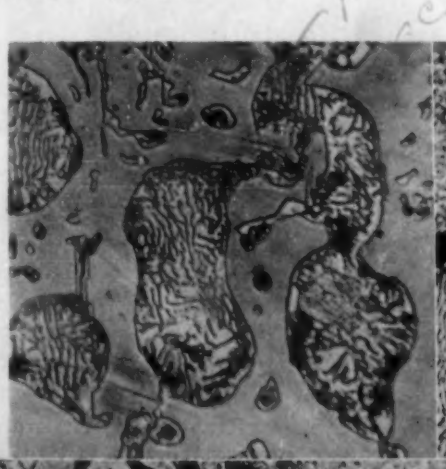


Fig. 3. Microstructure of Pearlitic Cast Iron. Mag. ×500. Etched.

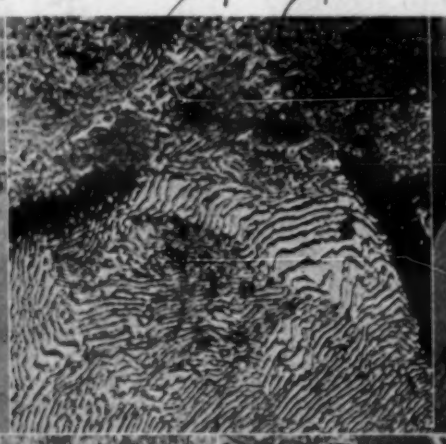


Fig. 4. Microstructure of Cast Iron showing Graphite, Pearlite and Ferrite. Mag. ×500. Etched.

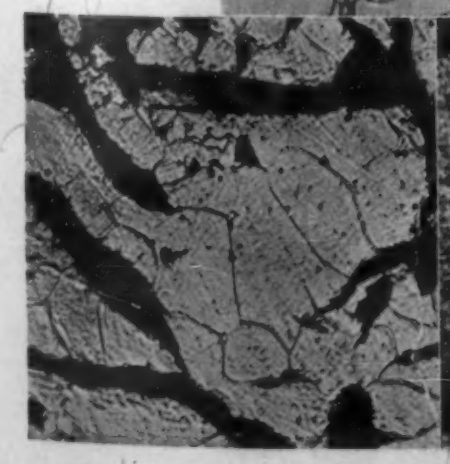


Fig. 5. Microstructure of Ferritic Cast Iron. Mag. ×500. Etched.

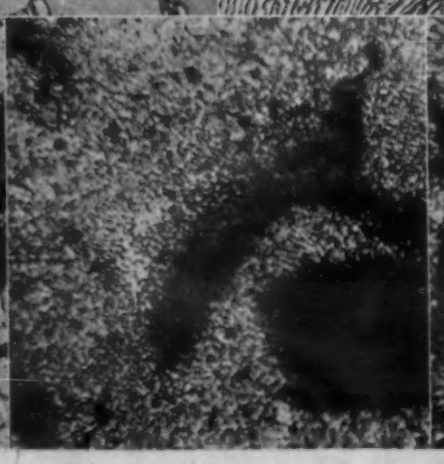


Fig. 6. Microstructure of Sorbitic Cast Iron. Mag. ×500. Etched.

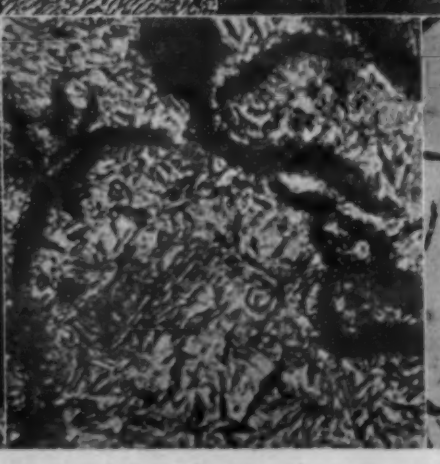


Fig. 7. Microstructure of Martensitic Gray Cast Iron. Mag. ×500. Etched.

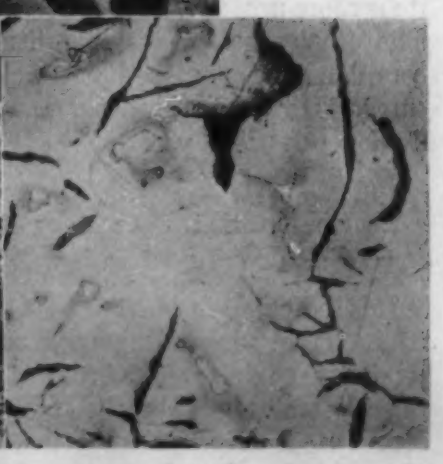


Fig. 8. Microstructure of Austenitic Cast Iron. Mag. ×500. Etched.

other (e. g., nickel, copper and aluminum). Carbide forming elements increase the temperature of beginning of graphitization of eutectic cementite as is also shown in Fig. 11. Since small proportions of manganese react with sulphur it is clear why the effect of this element is not apparent unless the percentage is greater than 0.75%

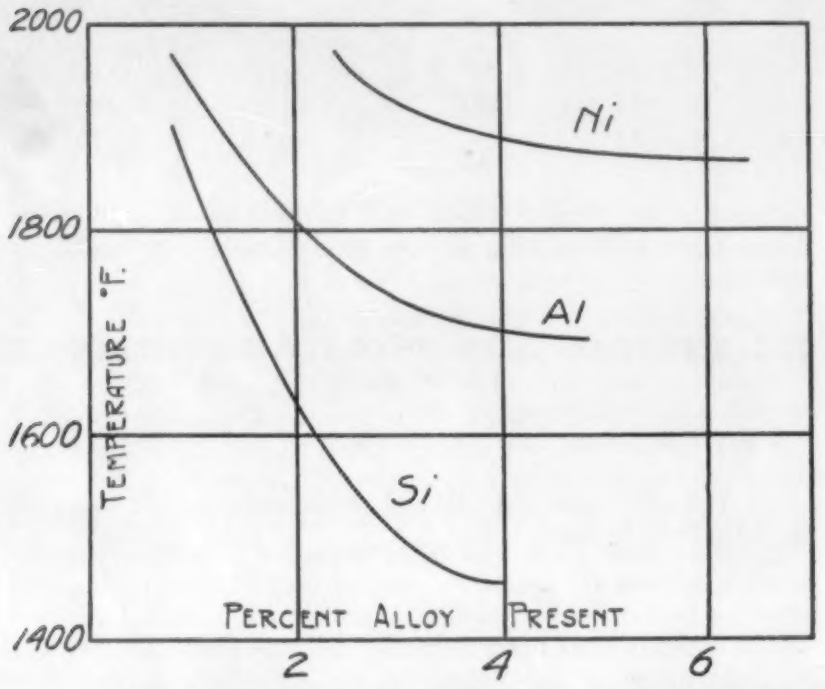


Fig. 9. Temperature of beginning of graphitization of eutectic cementite in white cast iron (Sawamura).

Total Carbon	**3.45%**
Silicon and impurities	**Nil**

After graphitization is once initiated the action at constant temperature is continued in three periods as follows:

First period: graphitization progresses at a slow rate.
Second period: graphitization progresses at an accelerated rate.
Third period: graphitization progresses at a slow rate to equilibrium.

This is plainly shown in Fig. 12[3] which also shows that graphitization is faster in a high carbon (graph A, 2.60% C) iron than in a low carbon (graph B, 2.30% C) iron. While the foregoing data relate primarily to the process of manufacture of malleable iron they are essential also in considering other heat treating processes. It is desirable in many instances that heating at elevated temperatures for short periods of time leave the original structure as little altered as possible. It is clear then, from Figs. 9 to 12, inclusive, that heating for short periods of time at temperatures as high as 1650° F. has little effect upon eutectic cementite, particularly in low carbon irons.

The effect of heat upon pro-eutectoid cementite (cementite of pearlite) is most important, especially in gray iron. Cementite is more unstable in the presence of graphite than otherwise. That is why, unlike steel, pearlitic cementite in gray iron can be completely decomposed at comparatively moderate temperatures. However, this action, as in the case of eutectic cementite depends upon:

1. Temperature.
2. Composition.
3. Time.

It is indicated in Fig. 13[4] that prolonged heating above 600° to 1000° F. (depending upon composition) causes eutectoid cementite to decompose into ferrite and graphite. The higher the silicon, the lower the temperature at which eutectoid cementite is decomposed by the action of heat. The presence of carbide forming elements such as chromium tends to inhibit the decomposition of eutectoid cementite. Fig. 14[4] shows that the effect of time is similar to the effect in the case of eutectic cementite. Addition of silicon accelerates; and addition of carbide forming elements decelerates the decomposition of the eutectoid carbide. However, the initial phase of decomposition is at such a slow rate that during the relatively short time that cast iron is subjected to heat in the ordinary process of annealing or heat treating any change which may occur is negligible, particularly in low Si irons.

The structures of one inch sections of step bars containing nickel and silicon are shown in Fig. 15.[5] These structures consist of sorbite, martensite and austenite and combinations of these structures. Through the action of heat over short periods of time at relatively high temperatures (1562° F.), as is shown in Fig. 16,[5] the tendency is for pearlite and sorbite as well as martensite to change to ferrite and graphite. Martensite-austenite and low alloy content austenite tend to change to martensite. High alloy content austenite is stable unless the temperature is lowered to 30° to 300° F. below zero (depending upon the exact composition).

THE CRITICAL RANGES OF CAST IRON

Studies of the critical ranges of cast iron[4, 6, 7, 8, 9, 10, 16] have been made by a number of investigators. Since some results have been reported as beginning and end and others as the maximum rate of change and since widely different methods of determination have been used as well, the recorded data vary widely. As in the case of steel, the initial stage of the critical range will depend upon the combined carbon present.

In Fig. 17 is shown the effect of silicon on the end points of the $Ac_{3,2}$ and Ar_1 ranges of cast iron with combined carbon

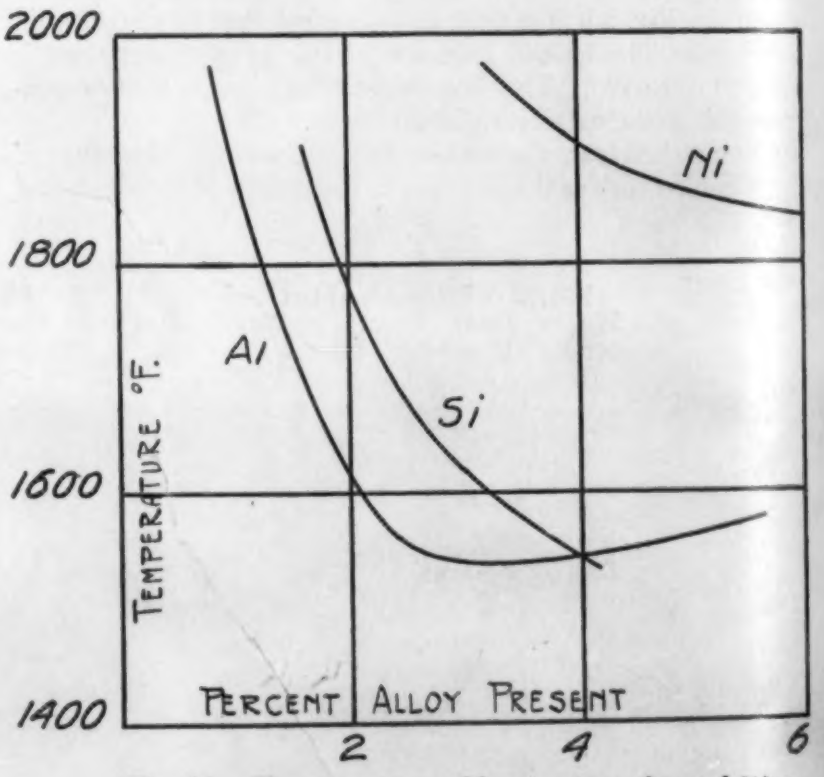


Fig. 10. Temperature of beginning of graphitization of eutectic cementite in white cast iron (Sawamura).

Total Carbon	**2.50%**
Silicon and impurities	**Nil**

between 0.55 and 0.90%. The effect of addition of silicon is to raise both the Ac and Ar critical ranges. One percent of silicon raises the temperature of the Ac range approximately 53° F.

The effect of nickel is to lower both the Ac and Ar critical ranges as is shown in Fig. 18. Each percent of nickel (up to 4.0%) lowers the $Ac_{3,2}$ range approximately 40° F. It is evident from Fig. 19 that the effect of silicon predominates over small percentages of nickel but as nickel is increased above 1.50% the effect of nickel predominates over silicon by lowering the critical ranges.

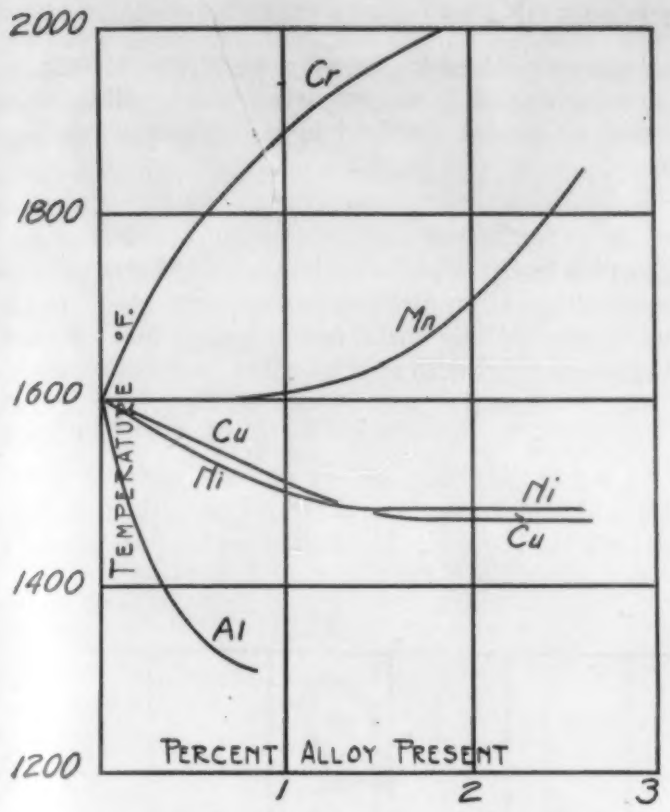


Fig. 11. **Effect of alloys on the temperature of beginning of graphitization of eutectic cementite of white cast iron in the presence of silicon (Sawamura).**

Total Carbon	**2.80%**
Silicon	**0.80%**

Effect of Cobalt—temp. uniform at 1652° F.
Effect of Tungsten—temp. uniform at 1634° F.
Effect of Molybdenum—temp. uniform at 1562° F.

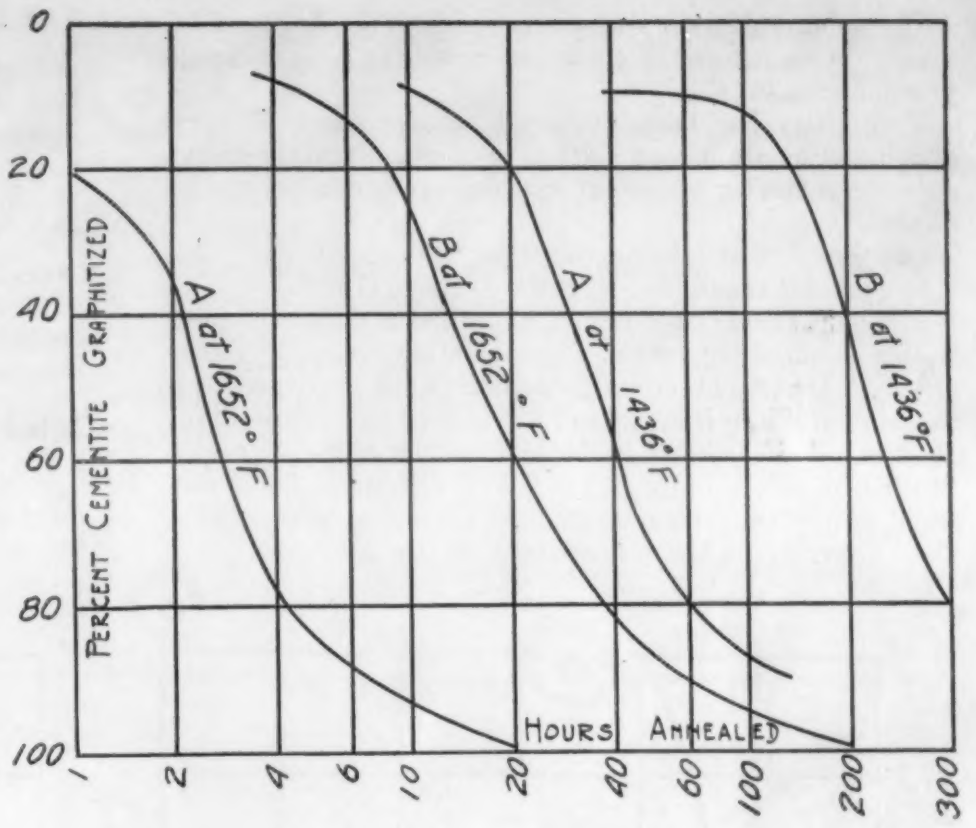


Fig. 12. **Graphitization of two white cast irons at constant temperature (Schwartz). Compositions not given.**

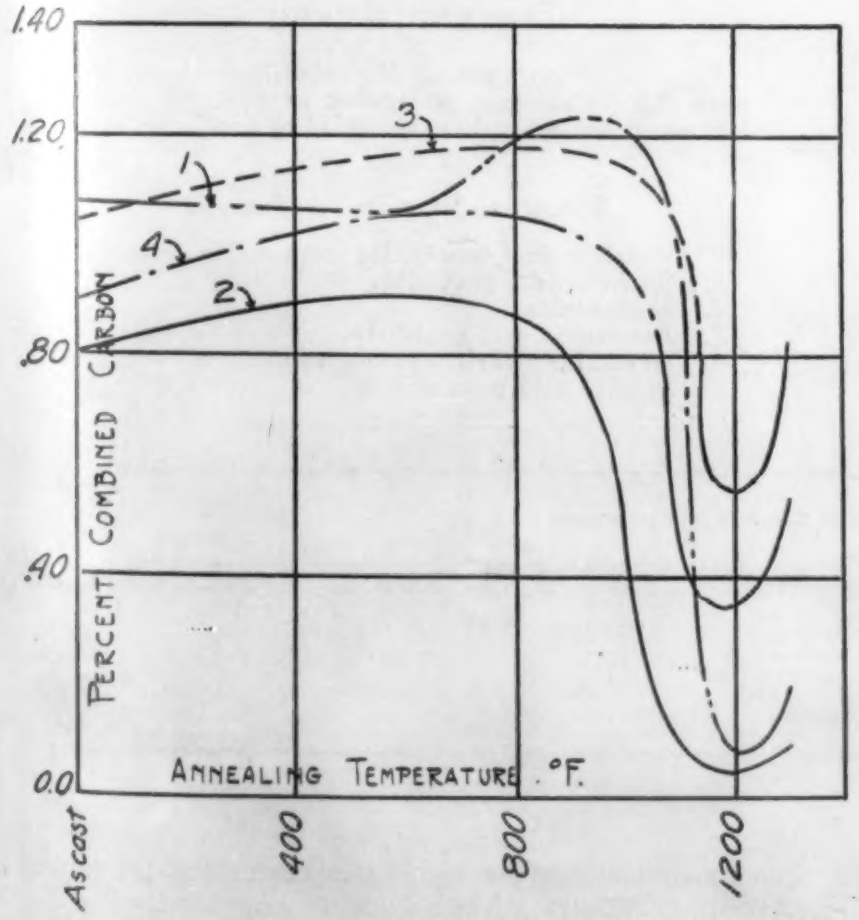


Fig. 13. **Effect of annealing for 90 hours at various temperatures on the combined carbon of plain and nickel-chromium cast iron.**

	Compositions in percent			
No.	**1**	**2**	**3**	**4**
Total Carbon	3.12	3.10	3.10	3.15
Silicon	1.08	1.69	1.13	1.76
Nickel	None	None	1.21	1.13
Chromium	None	None	0.39	0.45

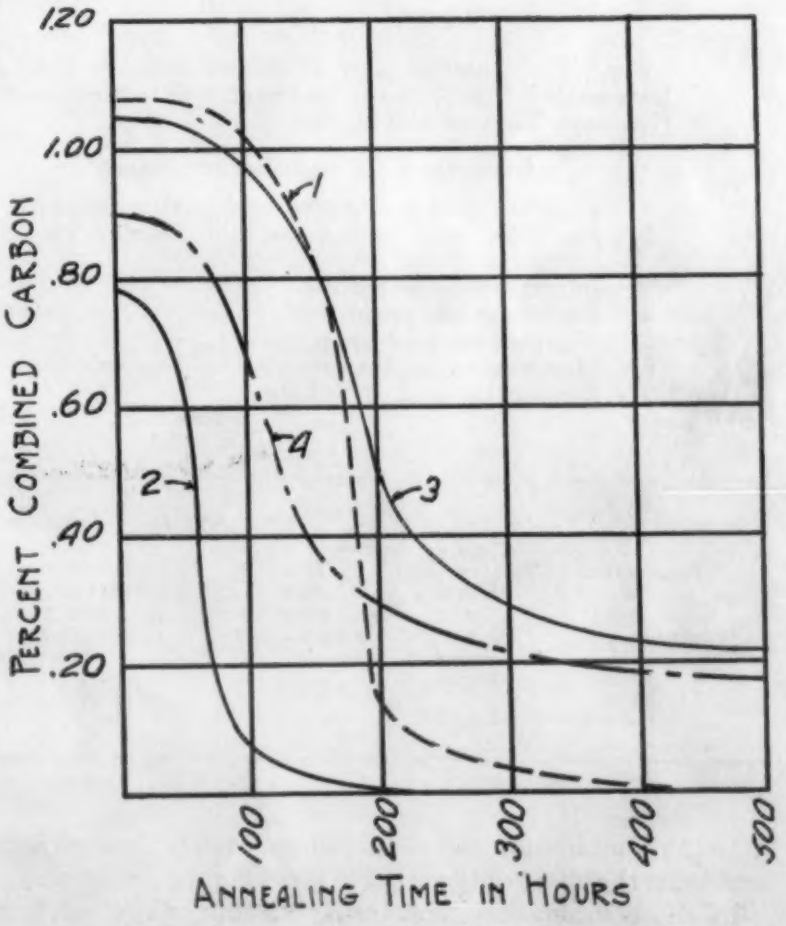


Fig. 14. **Effect of time annealing at 1100° F. on graphitization of cementite of pearlite.**

	Compositions in percent			
No.	**1**	**2**	**3**	**4**
Total Carbon	3.12	3.10	3.10	3.15
Silicon	1.08	1.69	1.13	1.76
Nickel	None	None	1.21	1.13
Chromium	None	None	0.39	0.45

Chromium raises the temperature of both the $Ac_{3,2}$ and Ar_1 ranges. One percent of chromium raises the $Ac_{3,2}$ range approximately 120° F.

Very little has been published on the effect of other alloying elements or combinations of them. From the known data the following somewhat speculative conclusions are indicated.

One percent molybdenum raises the Ac range 10° F.

One percent vanadium lowers the Ac range 175° F.

The joint effect of nickel and chromium is rather complex. With a balanced proportion of nickel and chromium ($2^1/_2$ parts nickel to 1 part chromium), chromium apparently predominates in low silicon iron (1.0 to 1.5% silicon) and the resultant effect is a slight increase in the temperature of the Ac range. In the high silicon range (2.0 to 2.20% silicon), nickel in balanced proportion predominates over chromium and causes a slight lowering of the temperature of the Ac range.

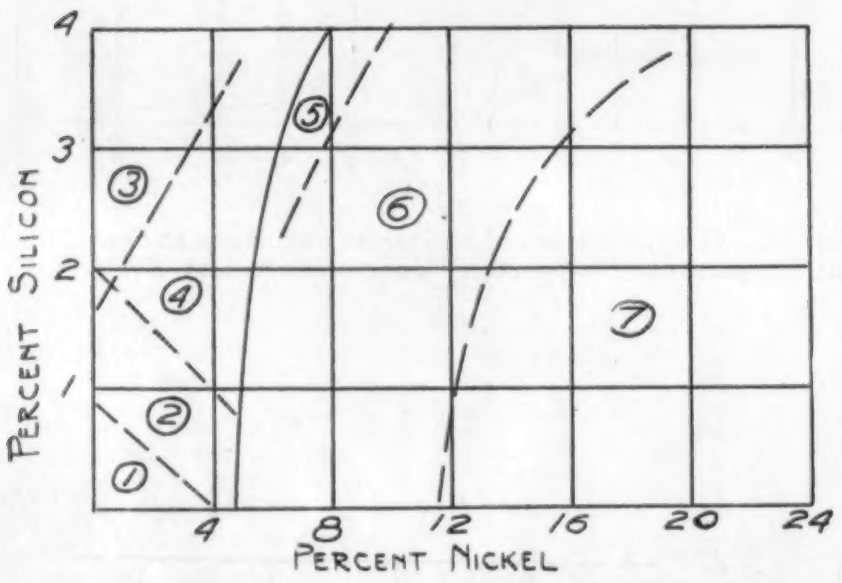


Fig. 15. Constitution of Nickel-Silicon-Iron Alloys with 3.5% Carbon. As cast. One inch section (Everest, Turner and Hanson).

Structure of numbered areas

1. Pearlite and austenite cementite eutectic.
2. Pearlite and pro-eutectoid cementite and graphite.
3. Pearlite and graphite.
4. Sorbite and graphite.
5. Martensite and graphite.
6. Martensite and austenite and graphite.
7. Austenite and graphite.

THE PURPOSES OF HEAT TREATMENT OF CAST IRON

The main purpose of heat treatment of cast iron is the alteration or enhancement of some properties which will increase its usefulness, or extend the field of its industrial application.

Baking

Castings which have been pickled in acid in order to remove sand or scale are usually quite brittle due, supposedly, to occluded hydrogen. Baking for a few hours at 300° F. will completely remove this brittleness.

Aging

In general, aging to relieve casting stresses without materially affecting physical properties is carried on in the temperature interval 800° to 1100° F. Data showing the practice used

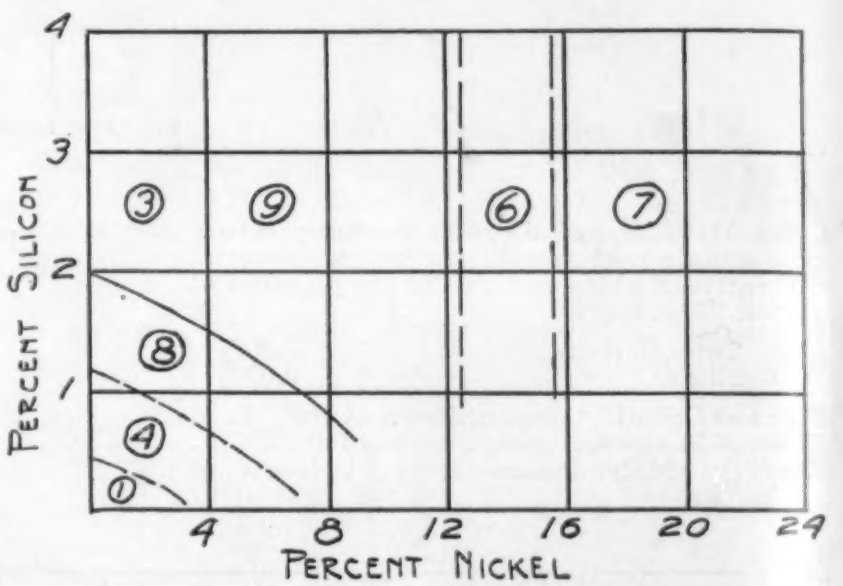


Fig. 16. Structure of Nickel-Silicon-Iron Alloys with 3.5% Carbon. Annealed at 1582° F. for one hour and cooled in furnace, taking one hour to cool to 1202° F.

Structure of numbered areas

1. Pearlite and austenite cementite eutectic.
4. Sorbite and graphite.
6. Martensite.
7. Austenite and graphite.
8. Granular pearlite and graphite.
9. Ferrite and graphite.

Table 1—Aging Cast Iron to Relieve Casting Stresses

Temperature, ° F.	Time at Temperature, Hours	Total Carbon, %	Chemical Composition					
			Manganese, %	Phosphorus, %	Sulphur, %	Silicon, %	Nickel, %	Chromium, %
800	4	3.50	0.55 to 0.75	0.20 max.	?	1.75 to 2.75	1.00	1.00
950 to 1100	1	3.25 to 3.42	0.45 to 0.75	0.17 to 0.30	0.075 to 0.10	1.85 to 2.25	....	....
975	varies	....	....	various	....	....	....	....
1000	varies	....	....	various	....	....	....	....
1000	3	3.00	0.60	0.20 max.	0.07	1.20	....	....
1050	3 to 5	....	....	various	....	....	....	....

In the combination nickel-vanadium, each of these elements augments the effect of the other in lowering the Ac range.

In the combination nickel-molybdenum, nickel predominates and effects a lowering of the temperature of the Ac range.

Both chromium and molybdenum in a combination of those elements jointly raise the temperature of the Ac critical range.

Since a thorough knowledge of the critical ranges is essential to intelligent heat treatment, extended investigation of the subject should prove fertile ground for future investigations.

by a number of industrial concerns are shown in Table 1.[12] Some manufacturers use higher temperatures at the expense of hardness and strength as is evident by considering Fig. 20,[11] which shows that annealing at 1450° F. causes a reduction of 33% in tensile strength and 23 to 26% in Brinell hardness. The length of time at temperature is also important, as is shown in Fig. 21.[11] Annealing at 1050° F. for 6 hours showed practically no effect on Brinell hardness while the same treatment at 1150° F. caused a reduction of 30% in hardness. Reference to Fig. 13 would indicate that the lower the silicon the higher the temperature at which rapid alteration of properties occurs, and that for the same silicon content the joint

presence of nickel and chromium slightly increases the temperature at which rapid change begins to occur. A similar effect is shown in Fig. 14.[4] The quantitative data regarding relief of stress by aging shown in Fig. 22[10] are interesting. They indicate that while a temperature of 1150° F. will relieve practically all stress, appreciable structural alteration occurs (growth following decomposition of cementite of pearlite). The best temperature to relieve maximum stress for this silicon content with minimum alteration of structure is 900° F. The effect of heating above 900° F. is further evidenced by the softening shown in Table 2.[12]

Rust Proofing

Cast iron can be more or less efficiently protected against rust or corrosion by:

1. Chemical treatment accompanied by heat.
2. Coating with non-corrosive metals applied by accompanied action of heat.

Many so-called rust proofing processes such as Parkerizing, Cosletizing, etc., require some action of heat, but the temperature is too low to have any definite effect upon the structure or properties of cast iron.

Some processes, however, require much higher temperatures.

Bluing is usually effected by heating at 900° F. in a bath consisting of 50% each of sodium and potassium nitrates followed by quenching in oil. Small quantities of potassium permanganate and manganese dioxide are often added to the nitrate bath.

Gun metal or black finish is accomplished in the same manner except that the heating temperature is 1000° F. A black finish is also obtainable by heating parts packed with carborizing material in boxes to 1200° F. and then quenching

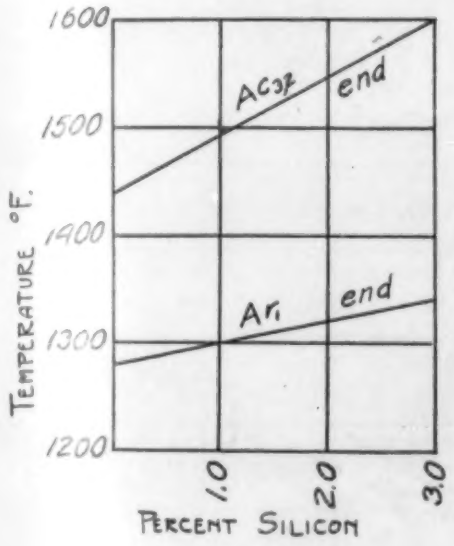


Fig. 17. **Critical ranges of plain cast iron containing 3.3% total carbon.**

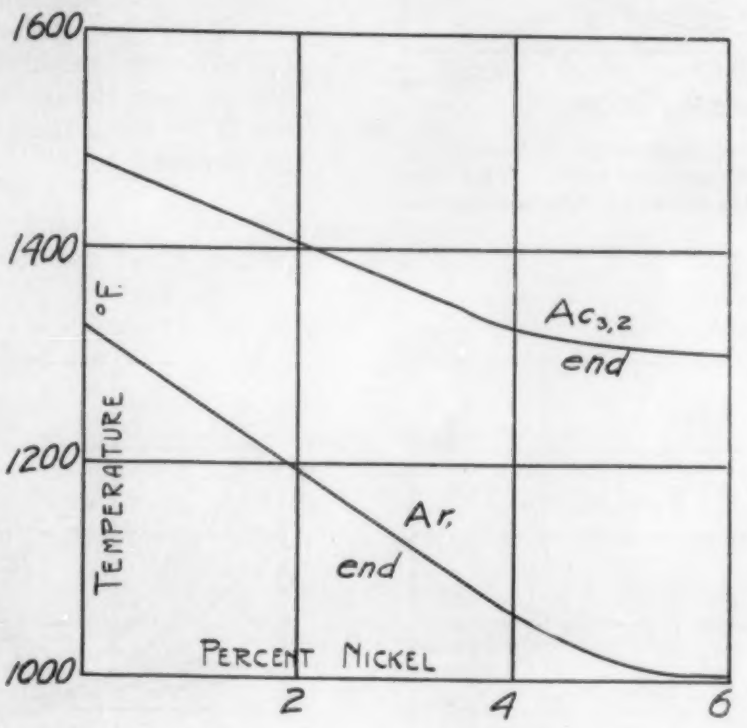


Fig. 18. **Effect of nickel on the critical ranges of cast iron containing 3.3% total carbon and 1.3% silicon.**

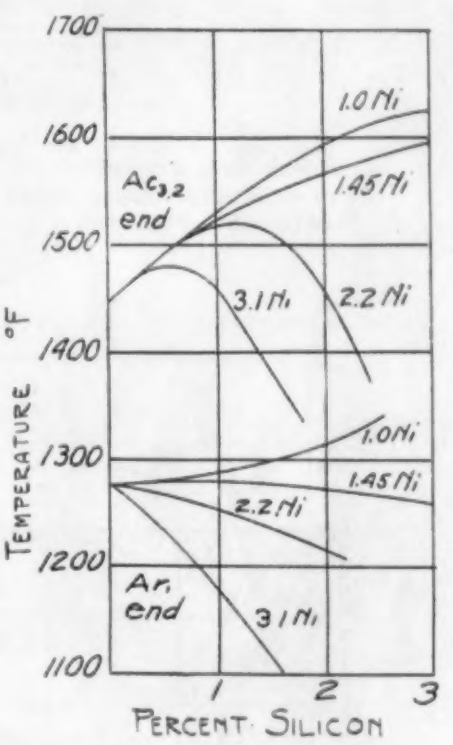


Fig. 19. **Effect of silicon on the critical ranges of cast iron containing 3.2 to 3.5% total carbon and various proportions of nickel.**

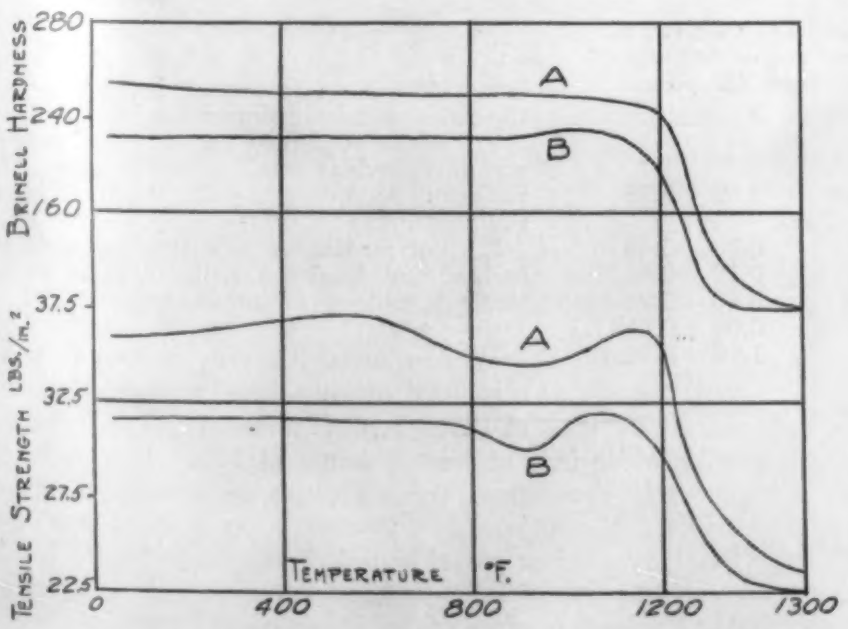


Fig. 20. **Properties of plain cast iron after annealing for one hour and cooling in the furnace (MacPherran and Harper).**

	Compositions	
No.	**A**	**B**
Silicon	1.44	1.69
Sulphur	0.123	0.10
Manganese	0.68	0.55

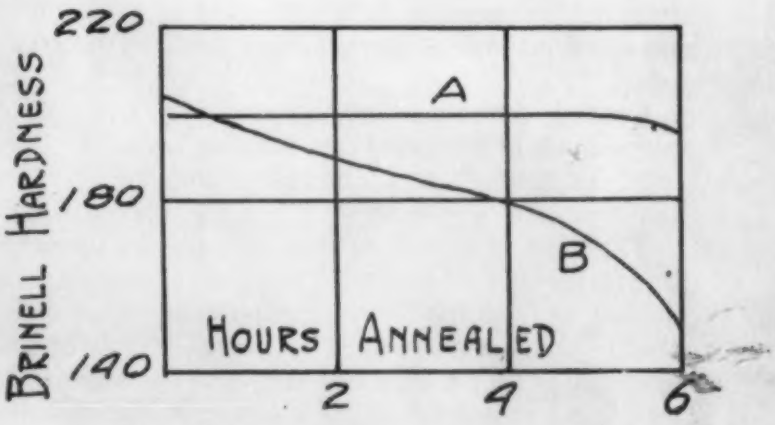


Fig. 21. **Effect of time of annealing on hardness of plain cast iron (MacPherran and Harper).**

No.	**A**	**B**
Silicon	1.32	1.32
Sulphur	0.097	0.097
Manganese	0.59	0.59
Annealing temp.	1050° F.	1150° F.

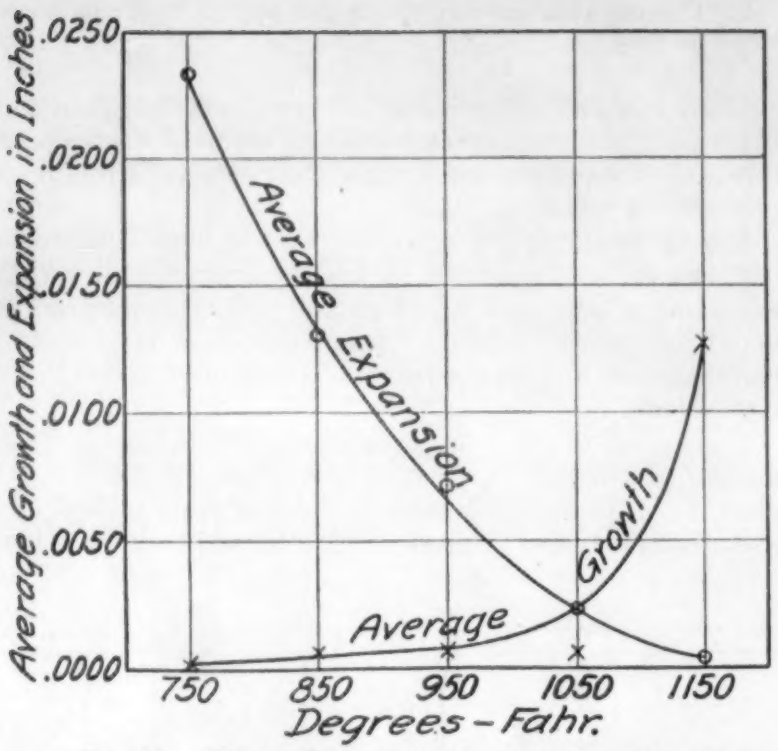


Fig. 22. Effect of annealing one to three hours on growth and expansion of stress-test bars. The less the expansion the greater the relief of internal stress (Walls and Hartwell).

Table 2—Effect of Annealing Temperature on the Hardness of Cast Iron

COMPOSITION: Total Carbon, 3.42%; Graphitic Carbon, 2.95%; Combined Carbon, 0.47%; Manganese, 0.77%; Phosphorus, 0.17%; Sulphur, 0.092%; Silicon, 1.87%.

Specimen	Annealed 1 Hour at ° C.	° F.	Brinell Hardness Number 10-mm. Ball, 3000-kg. Load	5-mm. Ball, 750-kg. Load	Scleroscope Hardness Number, Model D	Rockwell Hardness Number, "B" Scale, 1/16-in. Ball, 100-kg. Load
No. 1.....	as cast	as cast	201	206	37	93
No. 2.....	100	212	197	196	36	91
No. 3.....	200	392	201	206	37	93
No. 4.....	300	572	197	196	36	91
No. 5.....	400	752	197	196	36	90
No. 6.....	500	932	170	178	32	85
No. 7.....	600	1112	114	111	25	68
No. 8.....	700	1292	121	121	25	71

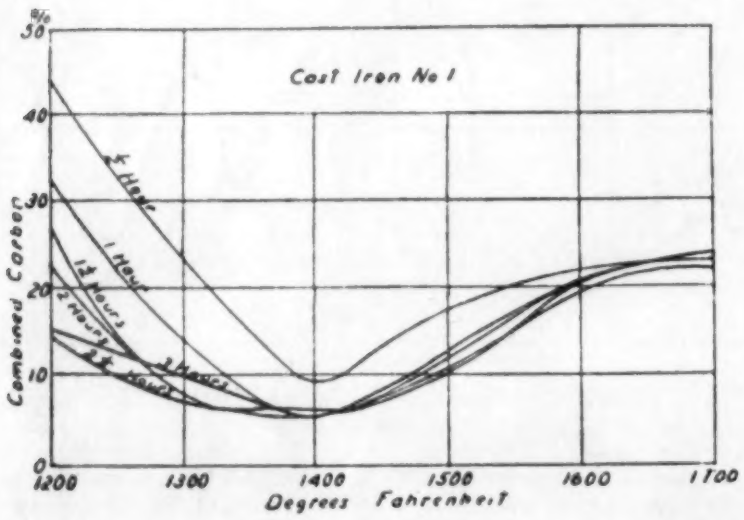
The practice in general commercial use by a number of manufacturers is shown in Table 3.[12] This practice covers a wide range of temperature, composition and application.

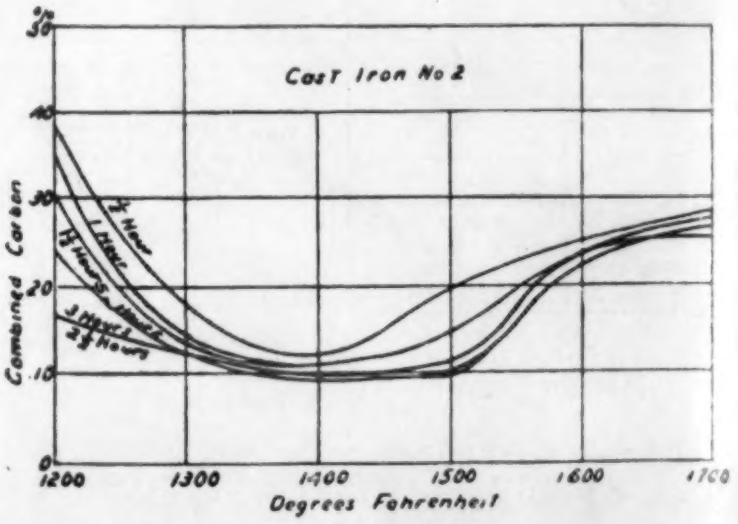
The effect of annealing at various temperatures on the hardness of gray iron is shown in Table 4[12] and Figs. 25 and 26.[14] The effect on combined carbon is shown in Figs. 23, 24,[13] 25 and 26[14] and the effect on tensile strength in Figs. 25, 26[14] and 27.[15] From these data the following general conclusions can be drawn.

1. The maximum softening effect is obtained by annealing between 1100° and 1550° F., the most desirable temperature being 1400° F. (However, this depends upon the exact chemical composition.)

2. While combined carbon and hardness are decreased as total carbon increases, the variation of strength with total carbon is insignificant.

3. For maximum reduction in combined carbon and hardness with little effect on strength, silicon should be below 1.50%.





Figs. 23 and 24. Effect of annealing on combined carbon of cast iron (Roth).

Compositions	as cast	
No.	1	2
Total Carbon	3.52	3.25
Combined Carbon	0.50	0.43
Manganese	0.75	0.92
Phosphorus	0.40	0.22
Sulphur	0.05	0.068
Silicon	1.75	2.70

in sperm oil. Another method is to immerse parts in a bath of copper sulphate until a layer of copper is deposited on the entire surface by precipitation. This is followed by heating at an elevated temperature until the copper coating is oxidized black.

Coating with zinc by sherardizing is carried out at temperatures ranging from 600° to 775° F. and dip galvanizing at temperatures above 800° F.

The effect of these ranges of temperature upon high silicon iron, especially for protracted periods of time, is to cause a reduction in both hardness and strength. When it is essential that hardness and strength be altered as little as possible it is desirable to keep silicon and carbon as low as possible and still maintain a gray fracture. Reference to Fig. 13 indicates that the addition of nickel and chromium in balanced proportion ($2^1/_2$ parts nickel to 1 part chromium) tends to minimize the deleterious effect of heat in these processes.

Annealing

Annealing is carried out essentially to reduce hardness and facilitate machining. However, these ends are accomplished at the expense of some strength.

While martensitic gray iron can be decomposed by annealing for 6 hours or more at 1250° F., it is necessary to anneal martensitic white iron at least 6 hours at 1700° F. in order to sufficiently decompose the structure to render machining possible.

Small typewriter parts, bodies of carpenters' wood planes and other parts of builders hardware which do not require either hardness or strength are annealed at 1400° to 1450° F. in order to obtain maximum machinability. Such an annealing treatment usually reduces Brinell hardness to 120 to 130 and permits machining speeds as high as 200 ft./min.

Malleableizing

The malleableizing of white cast iron is essentially a heat treating process, but since it has developed into an independent industry on a huge scale, and the literature on the sub-

Table 3—Softening Cast Iron by Annealing to Facilitate Machining

Temperature, ° F.	Time at Temperature, Hours	Chemical Composition: Total Carbon, %	Manganese, %	Phosphorus, %	Sulphur, %	Silicon, %	Remarks
1100 to 1200	?	....	various	various	....	....	Chilled rolls
1200 to 1250	?	....	various	various	....	....	Miscellaneous castings
1400	depends on size	....	0.60 to 0.90	0.20 to 0.40	0.07 to 0.10	.150	Large press frames and miscellaneous castings
1400	1	3.25 to 3.42	0.45 to 0.75	0.17 to 0.30	0.075 to 0.10	1.88 to 2.25	Pistons
1400 to 1450	1½	3.25 to 3.50	0.50 to 0.60	0.20 to 0.30	0.075 to 0.10	2.10 to 3.25	Pistons
1420 to 1475	varies	....	various	various	....	....	Miscellaneous castings
1450	1	3.40	0.65	0.65	0.09	2.80	Small castings in boxes
1450	2	3.50	0.70	0.40	0.10	2.50	Typewriter parts
1450	1 to 2	....	various	various	....	....	Miscellaneous castings
1500	5	....	various	various	....	....	Small castings
1500	½	....	0.40 to 0.80	0.20 to 0.55	0.08 to 0.13	1.30 to 2.30	Miscellaneous castings
1540	varies	3.55	0.54	0.58	0.078	2.42	Miscellaneous castings
1600	varies	....	gray iron	gray iron	....	....	Knitting machine parts
1600 to 1800	varies	3.40 to 3.70	0.50 to 0.70	0.40 to 0.80	0.05 to 0.08	1.60 to 2.00	Centrifugal pipe*
1300 to 1650	3	3.00 to 3.25	0.40 to 0.60	under 0.20	0.08 to 0.12	1.10 to 1.30	Large piston rings, small liners

* Chill cast (necessary to break down eutectic cementite).

ject is very voluminous, it can hardly be treated in the present discussion.

Toughening

White iron is usually quite brittle and it is often necessary to resort to annealing in order to obtain sufficient toughness to prevent breakage during handling or shipment. Grate bars containing less that 3.00% C, approximately 1.00% Si, 1.00 to 3.00% Ni and 0.50 to 1.00% Cr are white and brittle as cast. Annealing at 1500° to 1600° F. for 3 to 4 hours, followed by furnace cooling, will precipitate sufficient graphite to increase toughness and facilitate handling without breakage.

Quenching

When heated above the critical range and cooled at an accelerated rate (for instance, quenched) cast iron exhibits the same order of reactions that steel does if treated in the same manner. Quenching in oil or water develops a true martensitic structure. Drawing after quenching produces a reversion through troostite and sorbite to pearlite. Figs. 28, 29 and 30[4] show the structure of a low silicon iron as cast, after quenching in oil and after quenching and drawing at 800° F. Figs. 31, 32 and 33[4] show the structure of a medium silicon nickel-chro-

Table 4—Effect of Annealing Temperature on the Hardness of Cast Iron

COMPOSITION: Total Carbon, 3.42%; Graphitic Carbon, 2.95%; Combined Carbon, 0.47%; Manganese, 0.77%; Phosphorus, 0.17%; Sulphur, 0.092%; Silicon, 1.87%

Specimen	Annealed 1 Hour at ° C.	° F.	Brinell Hardness Number 10-mm. Ball, 3000-kg. Load	5-mm. Ball, 750-kg. Load	Scleroscope Hardness Number, Model D	Rockwell Hardness Number, "B" Scale, 1/16-in. Ball 100-kg. Load
No. 1.....	as cast	as cast	201	206	37	93
No. 2.....	400	752	197	196	36	90
No. 3.....	500	932	170	178	32	85
No. 4.....	600	1112	114	111	25	68
No. 5.....	700	1292	121	121	25	71
No. 6.....	800	1472	156	170	30	80
No. 7.....	900	1652	179	187	34	85
No. 8.....	1000	1832	179	187	34	85

NOTE.—½ in. of surface material removed after heat treatment before tests were made.

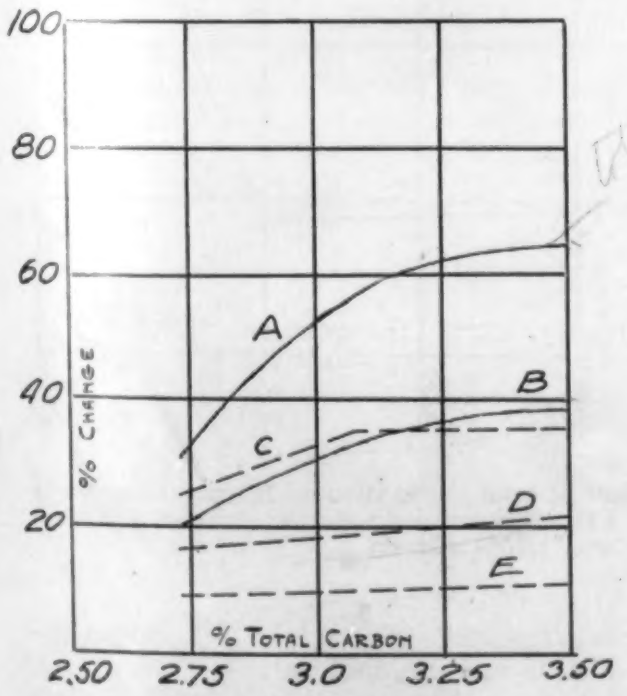


Fig. 25. Change of properties of plain cast iron of varying carbon content effected by annealing (Donaldson).

A—Carbon change at 1042° F.
B—Carbide change at 842° F.
C—Hardness change at 1042° F.
D—Hardness change at 842° F.
E—Strength change at 1042° F.

Composition

Manganese	0.89 to 1.06%
Phosphorus	0.34 to 0.41%
Sulphur	0.053 to 0.101%
Silicon	1.21 to 1.31%

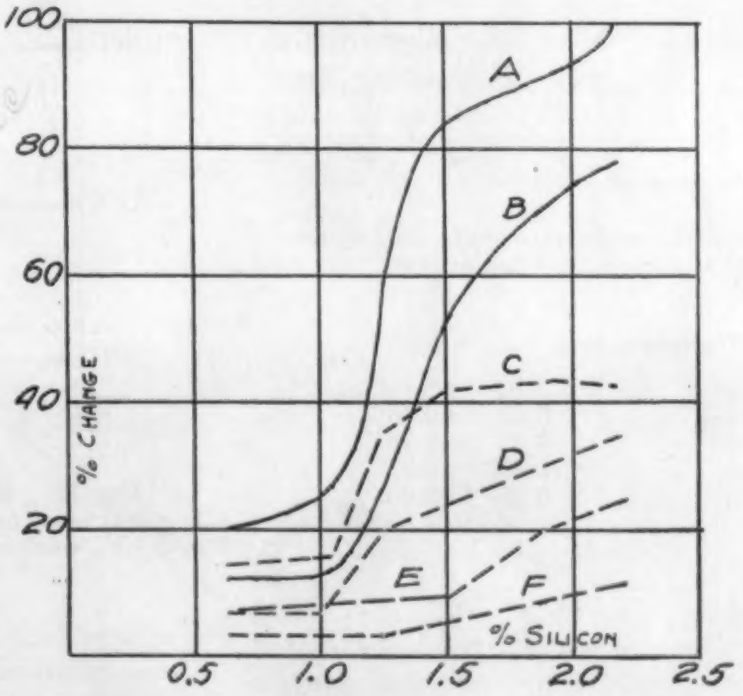


Fig. 26. Change of properties of plain cast iron of varying silicon content effected by annealing (Donaldson).

A—Carbide change at 1042° F.
B—Carbide change at 842° F.
C—Hardness change at 1042° F.
D—Hardness change at 842° F.
E—Strength change at 1042° F.
F—Strength change at 842° F.

Composition

Total Carbon	3.07 to 3.35%
Manganese	0.57 to 0.97%
Phosphorus	0.17 to 1.01%
Sulphur	0.054 to 0.12%

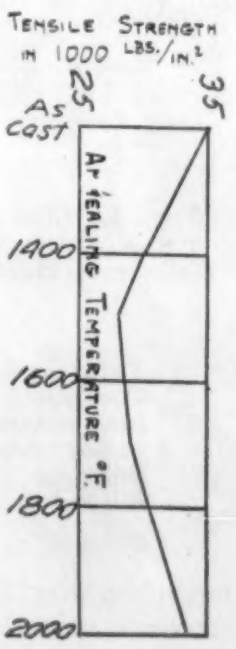


Fig. 27

Composition

Total Carbon	3.10
Manganese	0.45
Phosphorus	0.18
Sulphur	0.12
Silicon	1.10

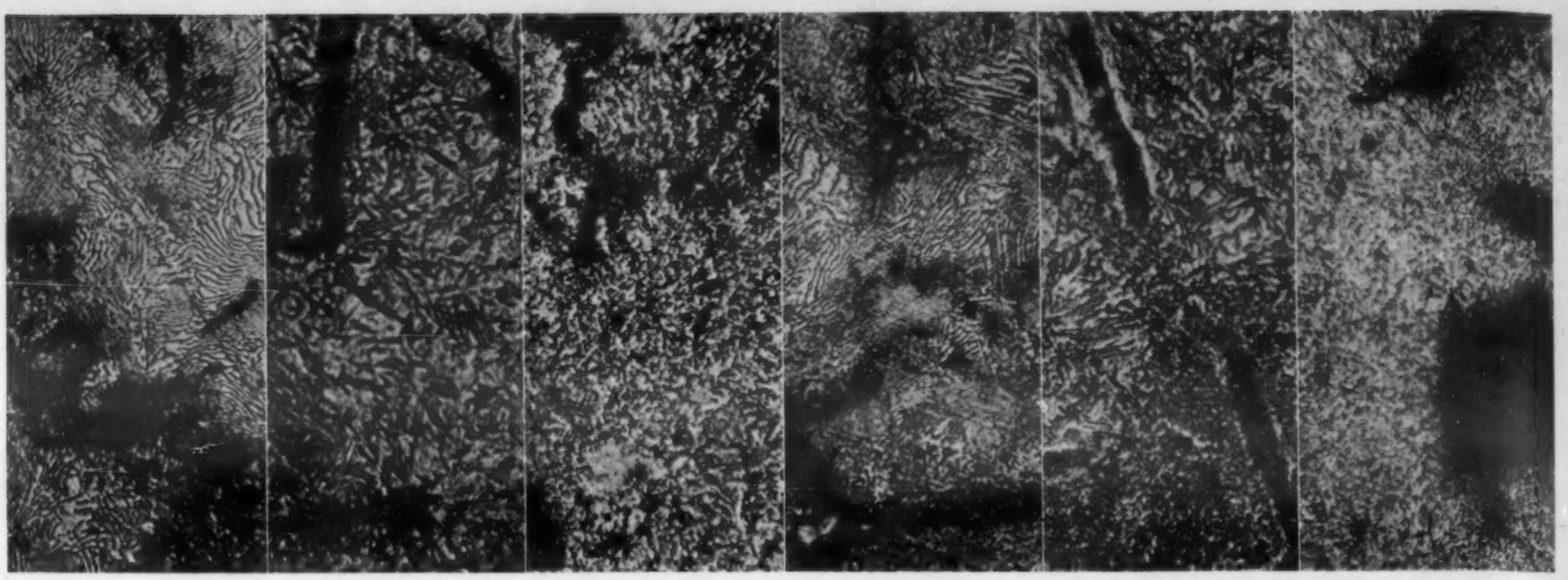


Fig. 28. Low silicon cast iron as cast. Pearlitic Mag. ×500. Etched.

Fig. 29. Low silicon cast iron quenched in oil from 1500° F. Martensitic. Mag. ×500. Etched.

Fig. 30. Low silicon cast iron quenched in oil from 1500° F. and drawn at 800° F. Sorbitic. Mag. ×500. Etched.

Fig. 31. Medium silicon nickel-chromium cast iron as cast. Pearlitic. Mag. ×500. Etched.

Fig. 32. Medium silicon nickel-chromium cast iron quenched from 1500° F. Martensitic. Mag. ×500. Etched.

Fig. 33. Medium silicon nickel - chromium cast iron quenched in oil from 1500° F. and drawn at 800° F. Sorbitic. Mag. ×500. Etched.

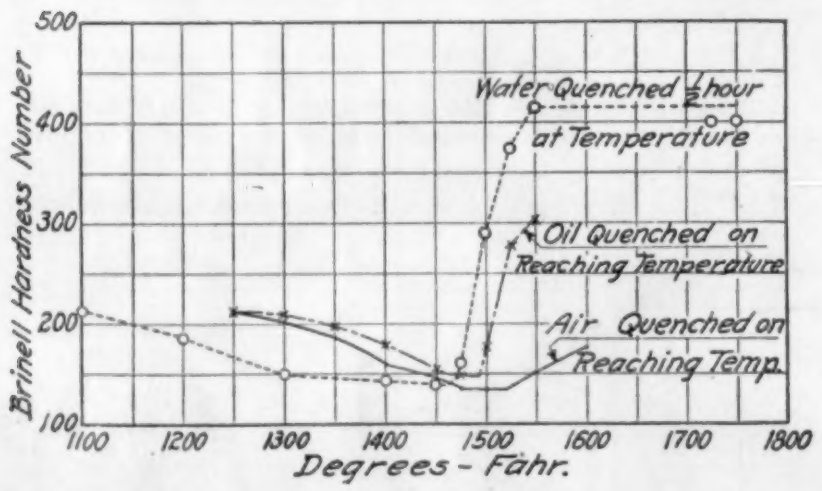


Fig. 34. Effect of quenching temperature and quenching medium on Brinell hardness of high silicon cast iron (Walls and Hartwell).

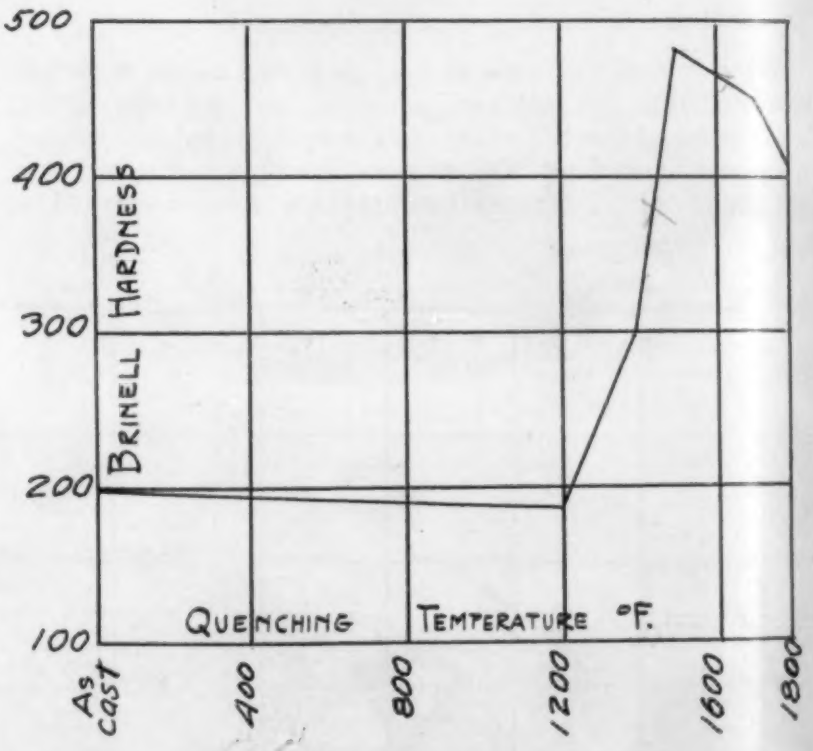


Fig. 35. Effect of quenching into oil from various temperatures on Brinell hardness of cast iron containing 3.10% carbon and 1.10% silicon.

Composition

Total Carbon	3.30 to 3.35%
Combined Carbon	0.52 to 0.55%
Manganese	0.70 to 0.75%
Phosphorus	0.202 to 0.210%
Sulphur	0.081 to 0.087%
Silicon	2.27 to 2.33%

mium iron after identically the same treatments. The original structure in each case was pearlitic, after quenching the structure was martensitic and after quenching and drawing, in both cases, the structure was sorbitic. It will be noted that in all corresponding instances, although silicon was comparatively high, the structure of the nickel-chromium iron was much finer than that of the plain low silicon iron.

As can be expected after viewing the effect of quenching upon structure, a corresponding effect upon hardness is obtained through the same process. Fig. 34[10] shows that quenching from various temperatures into different media causes Brinell hardness of a high silicon iron to vary with treatment. Fig. 35[15] shows the effect of oil quenching on the hardness of a low silicon iron. The variation of hardness with quenching temperature of medium silicon nickel irons is shown in Fig. 36.[17] The effect of oil quenching on nickel-chromium cast iron is shown in Fig. 37[10] and of water quenching on chromium-molybdenum iron in Fig. 38.[10] Silicon is so high and manganese relatively high in cast iron that water quenching is too drastic and tends to cause checks or fine cracks on the surface of pieces treated.

In the diagram, Fig. 39,[4] is shown a comparison of the relative response of various types of iron to oil quenching. Each iron was quenched from 50° F. above its upper critical range. The diagram indicates the following general facts:

1. Low silicon irons respond to heat treatment better than high silicon irons.
2. Nickel iron shows better response than plain iron of otherwise the same composition.
3. Nickel-chromium irons (particularly low silicon or low carbon) respond better to heat treatment than either plain iron or nickel iron.

Simple quenching in order to increase hardness is applied to

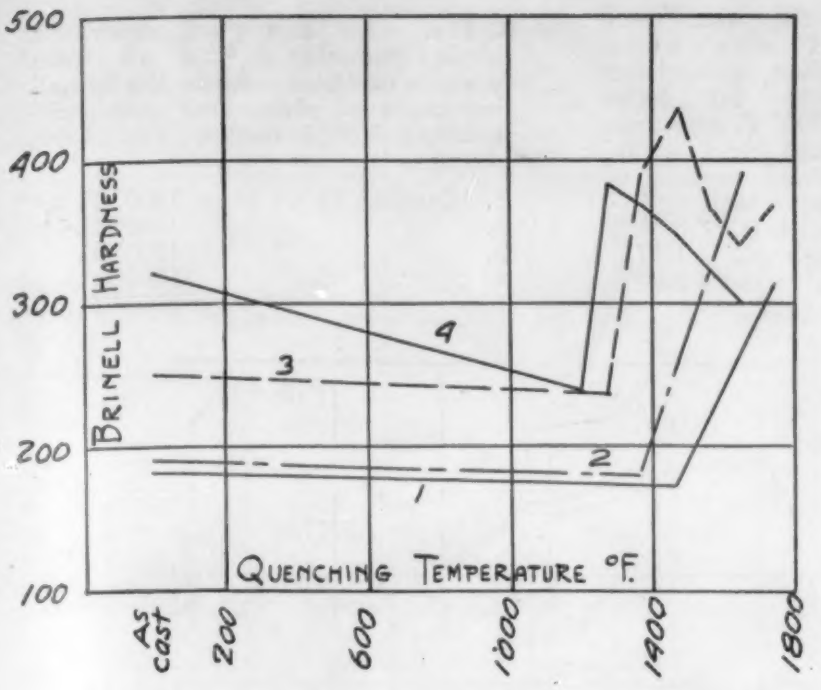


Fig. 36. **Effect of quenching from various temperatures into oil on Brinell hardness of plain and nickel cast iron (Guillet, Galibourg and Ballay).**

Compositions

No.	1	2	3	4
Total Carbon	3.38	3.12	3.42	3.07
Silicon	2.00	1.46	1.80	1.70
Nickel	0.00	1.15	3.32	5.07

shoe levelers and cams in shoe machinery, a Brinell hardness greater than 400 being desired in order to resist wear and prevent denting.

Quenching Followed by Drawback

The variation of Brinell hardness with drawback temperature after hardening is shown in Figs. 40,[15] 41[4] and 42[4] for both plain, nickel and nickel-chromium cast irons. These graphs are of the same general type as for heat treated steel.

The effect of quenching upon the tensile strength of a low

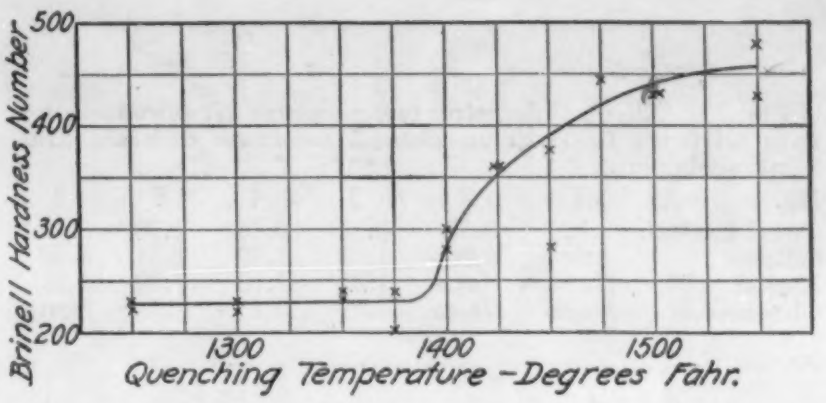


Fig. 37. **Effect of quenching into oil on Brinell hardness of nickel-chromium cast iron (Walls and Hartwell).**

Composition

Total Carbon	3.06 to 3.34%
Manganese	1.05 to 1.10%
Silicon	2.10 to 2.23%
Nickel	1.05 to 1.17%
Chromium	0.64 to 1.03%

silicon plain iron is given in Fig. 43[15] and shows that as the quenching temperature is raised above 1400° F. the tensile strength falls off progressively. Fig. 44[15] shows the effect of drawback on the same iron. Figs. 45 and 46[18] show similar data for three high silicon nickel-chromium irons. It is apparent from these data that:

1. Reheating after quenching within a definite range of temperature effects an augmentation in tensile strength.
2. The higher the quenching temperature the higher the temperature of drawback required to produce maximum tensile strength.
3. Quenching in oil from above the upper critical range and reheating to between 600° and 800° F. increases tensile strength above that in the "as cast" condition. It is probable that the extent of increase in strength depends upon the exact chemical composition.

As shown in Table 5,[4] the high strength alloy type of cast iron shows particular response to heat treatment. Oil quenching from above the critical range, followed by drawback be-

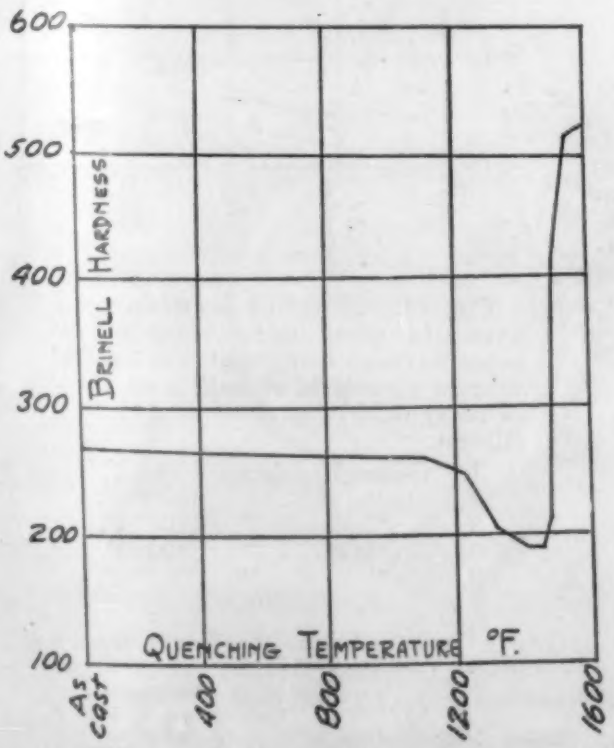


Fig. 38. **Effect of quenching into water on hardness of chromium-molybdenum cast iron (Walls and Hartwell). Composition: total carbon, 3.28 to 3.39%; manganese, 0.71 to 0.84%; silicon, 2.16 to 2.23%; chromium, 0.16 to 0.22%; molybdenum, 0.68 to 0.78%.**

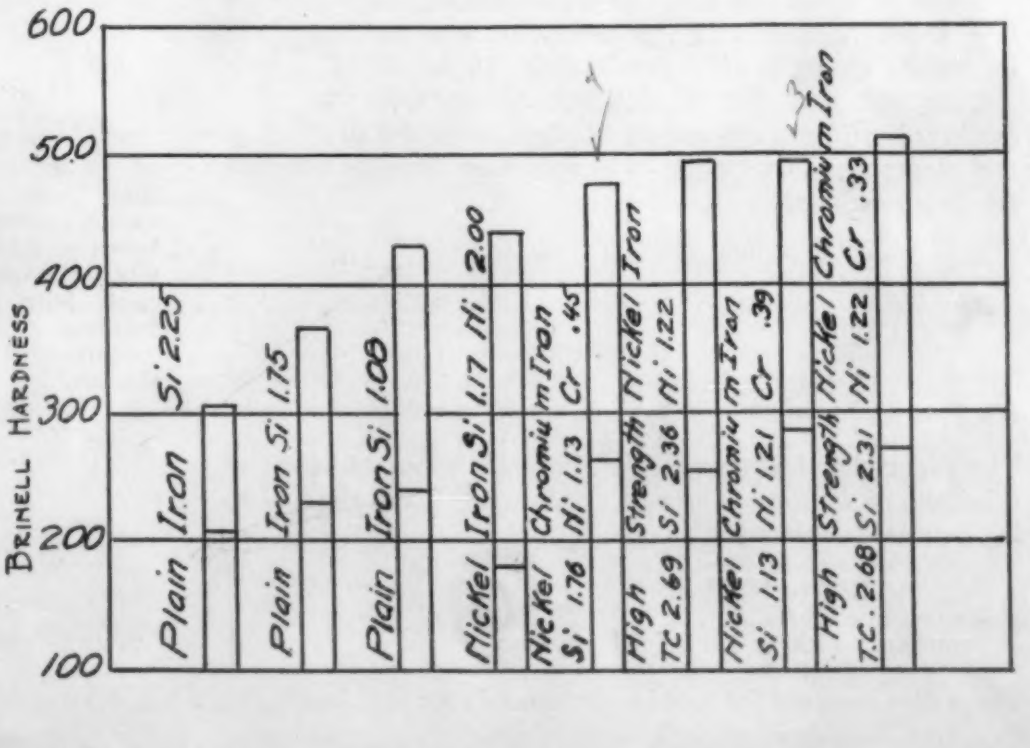

600
500
400
300
200
100
BRINELL HARDNESS
Plain Iron Si 2.25
Plain Iron Si 1.75
Plain Iron Si 1.08
Nickel Iron Si 1.17 Ni 2.00
Nickel Si 1.76
Chromium Iron Ni 1.13 Cr .45
High Strength Nickel Iron Tc 2.69 Si 2.36 Ni 1.22
Nickel Chromium Iron Si 1.13 Ni 1.21 Cr .39
High Strength Nickel Chromium Iron Tc. 2.68 Si 2.31 Ni 1.22 Cr .33

Fig. 39. **Graphic representation that alloy iron and particularly nickel-chromium irons develop greater hardness than plain iron when quenched in oil. Lower division of each column represents the hardness of the "cast" condition.**

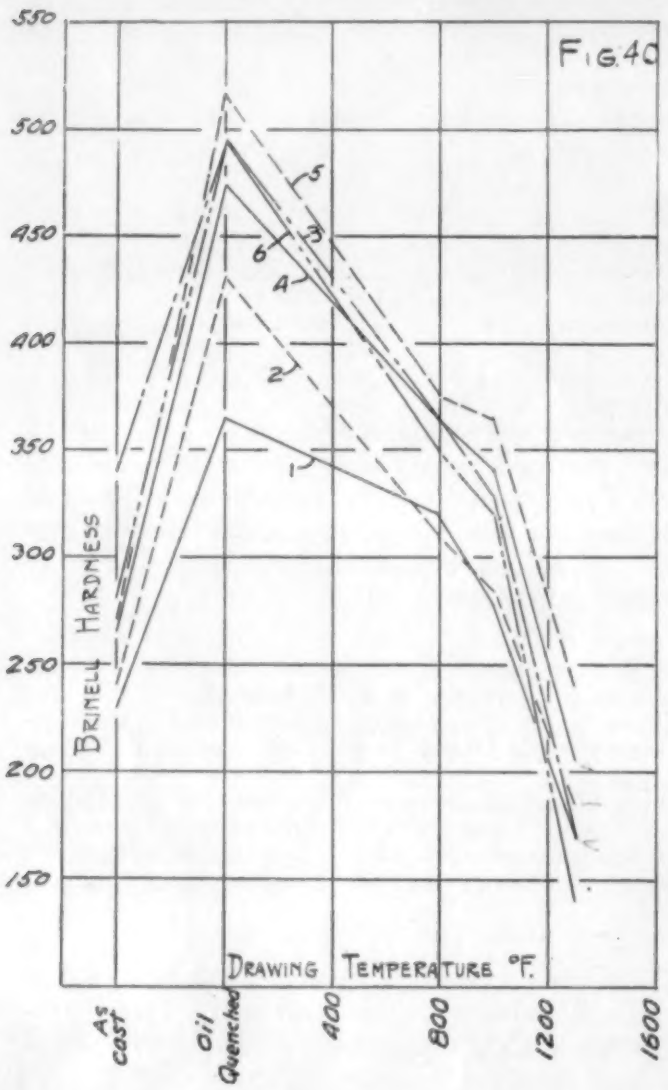
Fig. 40. Effect of drawing temperature after quenching into oil from 1500° F. on Brinell hardness of plain and alloy cast iron.

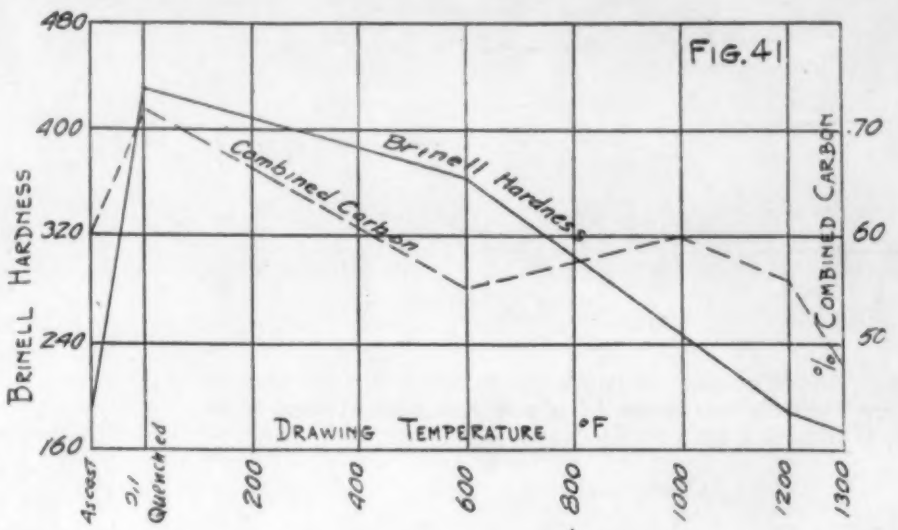
No.	1	2	3	4	5	6
Total Carbon	3.10	3.12	3.10	3.15	2.68	2.69
Silicon	1.69	1.08	1.13	1.76	2.31	2.36
Nickel	None	None	1.21	1.13	1.22	1.22
Chromium	None	None	0.39	0.45	0.33	None

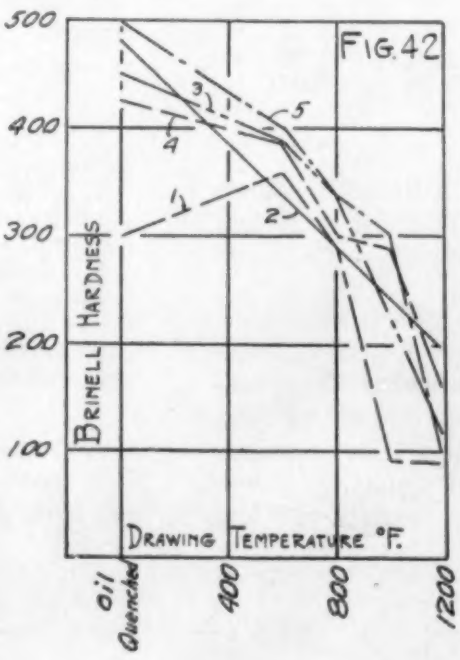
Fig. 41. Effect of drawback after quenching into oil from 1500° F. on hardness and combined carbon of cast iron containing 3.51% carbon, 1.17% silicon and 2.00% nickel.

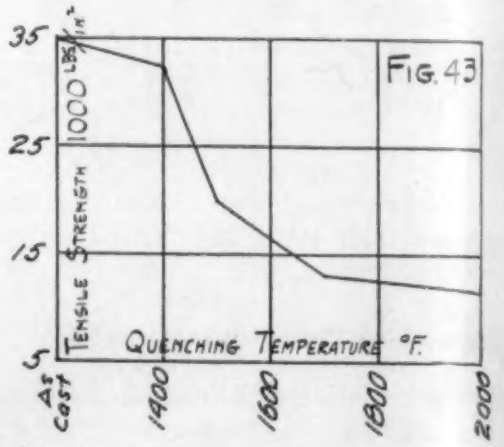
Fig. 42. Effect of drawback after quenching into oil from various temperatures on the Brinell hardness of plain cast iron containing 3.10% carbon and 1.0% silicon.

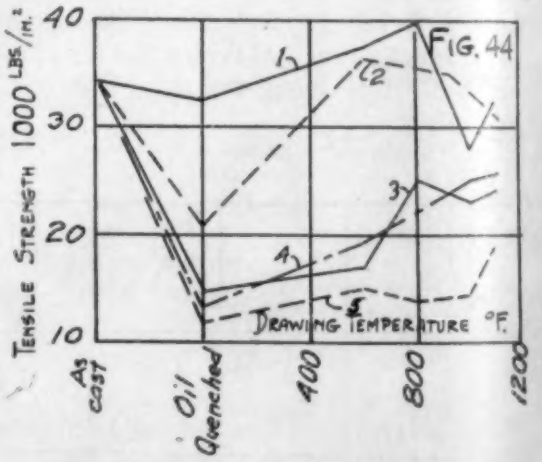
1. Quenched in oil from 1400° F.
2. " " " " 1500° F.
3. " " " " 1700° F.
4. " " " " 1800° F.
5. " " " " 2000° F.











tween 600° and 800° F., produces an increase in tensile strength of approximately 15 to 40%.

Quenched and drawn nickel-chromium cast iron castings have been extensively applied as dies for drawing and stamping sheet metal. The following range of composition has been used:

Total carbon	2.70 to 3.30%
Manganese	0.50 to 0.80%
Phosphorus	Under 0.25%
Sulphur	Under 0.12%
Silicon	0.90 to 1.60%
Nickel	2.50 to 3.50%
Chromium	0.50 to 1.00%

The exact chemical composition depends upon the size and thickness of the die. These dies are usually given the following thermal treatment.

Heat to 1550° to 1650° F.
Quench in oil.
Drawback to 300 to 350 Brinell hardness.

These dies are used for forming automobile bodies, headlight reflectors, household utensils, parts of agricultural machinery, stoves and furnaces, cafeteria trays and general sheet metal stamping and forming. They are also used for hot heading railway spikes, forming shovel blades and shanks, and drop forge dies requiring a limited number of impressions. The advantage of this type of die is that the tendency of sheet

Fig. 43. Effect of quenching into oil from various temperatures on the tensile strength of cast iron containing 3.10% carbon and 1.1% silicon.

Fig. 44. Effect of drawing temperature after quenching in oil from various temperatures on the tensile strength of cast iron containing 3.10% carbon and 1.10% silicon.

1. Quenched from 1400° F.
2. " " 1500° F.
3. " " 1700° F.
4. " " 1800° F.
5. " " 2000° F.

Table 5—Effect of Quench and Drawback upon the Tensile Strength of High Strength Nickel Cast Iron

Specimen	Composition: Total Carbon, %	Silicon, %	Nickel, %	Tensile Strength in lbs./in.² Quenched Oil 1500° F.: Original as Cast	Drawn at 600° F.	Drawn at 800° F.
No. 1.....	2.46	1.98	2.44	59,300	84,700	88,320
No. 2.....	2.84	1.98	1.44	55,600	75,560	78,840
No. 3.....	2.78	1.79	2.28	68,000	84,600	84,240
No. 4.....	2.89	2.02	2.44	66,200	75,560	78,840
No. 5.....	2.68	2.26	2.69	64,200	72,000	73,400
No. 6.....	2.81	2.02	3.08	69,606	63,200	82,100
No. 7.....	2.56	3.06	3.14	60,100	69,200	75,960

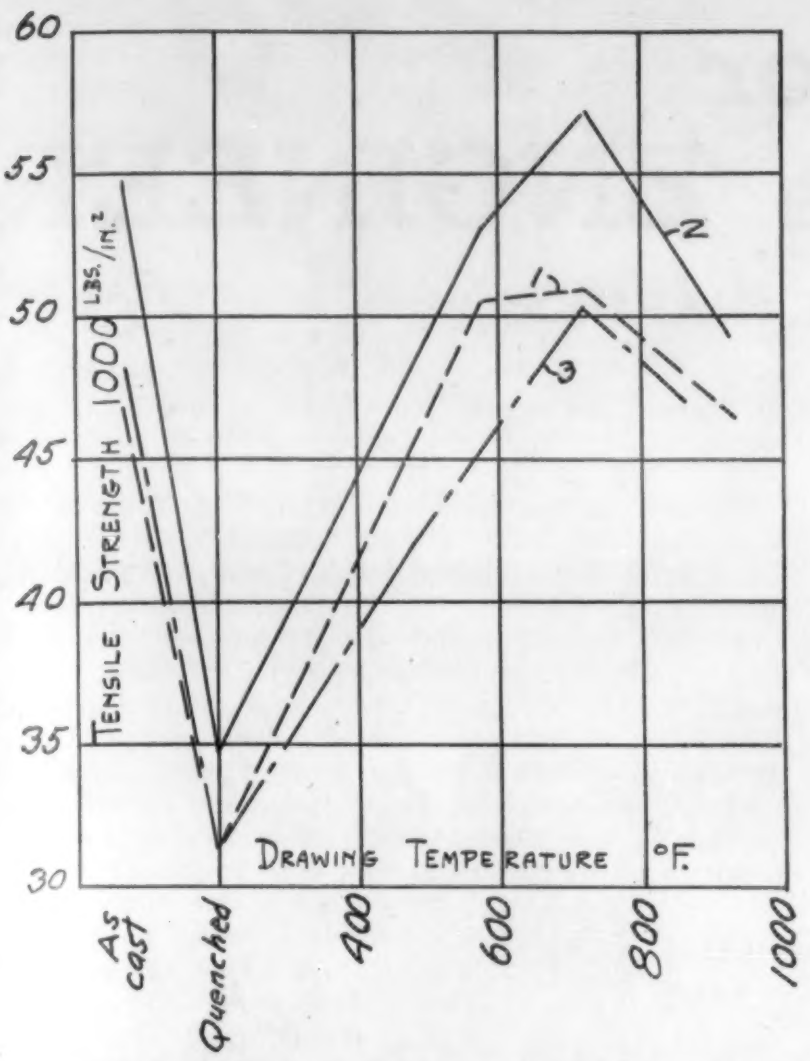


Fig. 45. Effect of quench and drawback on Brinell hardness of nickel-chromium cast iron piston rings (Hurst).

No.	1	2	3
Total Carbon	3.36	3.35	3.39
Silicon	2.30	2.07	2.09
Nickel	1.32	2.56	3.37
Chromium	0.44	0.95	0.61
Quenching medium	Oil	Oil	Air

metal to gall or pack is eliminated and they outlast plain iron dies 10 to 40 times. An English producer heat treats Diesel engine liners containing 2.50% nickel and 0.50% chromium to a Brinell hardness of 420 in order to reduce wear.

Carburizing

At least two manufacturers in the United States subject cast iron parts to the following carburizing process:

1. Pack in bone black or leather chips.
2. Heat for 4 hrs. at 1750° F.
3. Cool in pots.
4. Reheat to 1450° F. in lead pots.
5. Quench in brine.
6. Draw at 430° F.

Small parts for textile machinery, latches and trips for surface grinders and automatic screw machines, are given this treatment in order to better resist wear and impact.

CONCLUSIONS

The application of some forms of heat treatment of cast iron has been extensively adopted for some time by various industries, in particular the processes of artificial aging and annealing to facilitate machining. More recently and to a limited extent, quenching or quenching followed by drawback has been adopted for certain specific purposes. While the extent of the application of heat treatment of cast iron can be considered comparatively limited at the present time and the amount of data available rather meagre, the possibilities are promising and at the same time an interesting field for

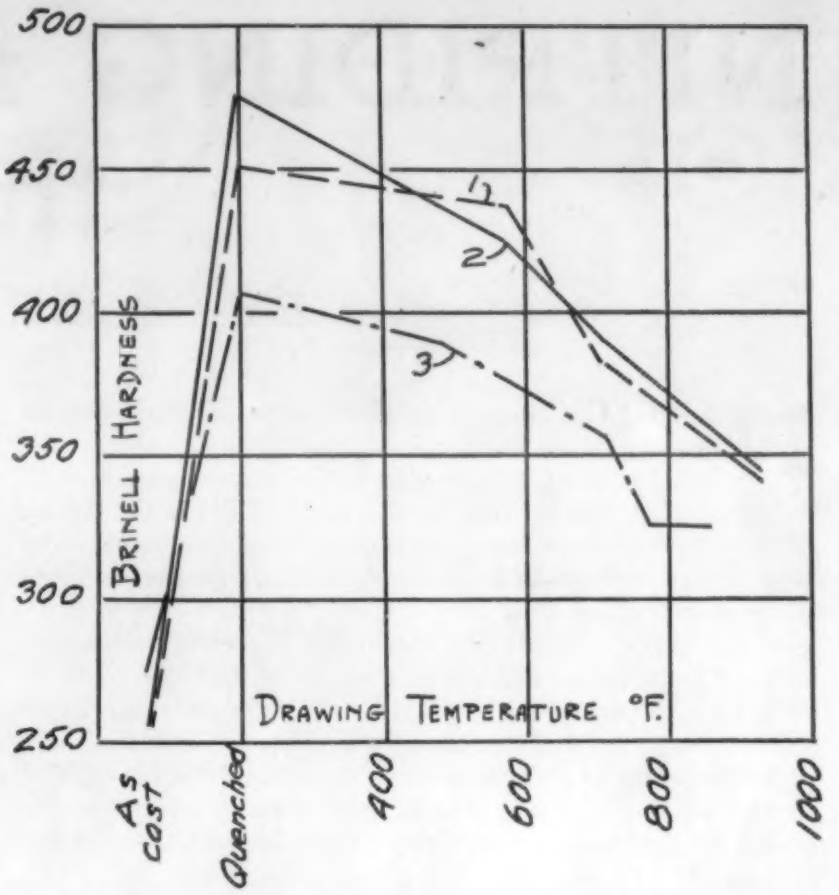


Fig. 46. Effect of quench and drawback on tensile strength of nickel-chromium cast iron piston rings (Hurst).

No.	1	2	3
Total Carbon	3.36	3.35	3.39
Silicon	2.30	2.07	2.09
Nickel	1.32	2.56	3.37
Chromium	0.44	0.95	0.61
Quenching medium	Oil	Oil	Air

future extension of the applications of cast iron in industry presents itself as a fertile possibility.

ACKNOWLEDGMENT

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NITRIDING for the ENGINEER

BY OSCAR E. HARDER*

NOT so long ago, one of the editorial staff was asked by an engineer whom one might have expected to know the answer, "What's this 'nitriding' all about anyway?" At a recent technical meeting, the head of one of our great steel companies introduced the author of a paper on nitriding, and stumbled over the pronunciation of the word. Evidently, the accountants had not yet put any figures on his balance sheets to lead him to make inquiry as to what nitriding is.

It is true that nitriding is but an infant, but it is a lusty one, and no user of metals who is worried by the problem of wear-resistance should fail to consider the possibilities of this new process. This article should answer the engineer's question.

NITRIDING as a commercial means of producing an extremely hard surface on steel is only about five years old. The invention of the process as it is used at the present time is credited to Dr. Adolf Fry of the Krupp Works, Essen, Germany. During the past five years, however, many investigators have contributed to the development of this process.

Many papers have been published. My own card index, which I know to be incomplete, contains about three hundred references to papers dealing with nitriding. Notwithstanding the large number of papers which have been published, it is still difficult for the engineer who is not directly engaged in research work in this field to know what steels are available and lend themselves advantageously to the nitriding treatment, how the nitriding process is carried out to the best advantage to produce a required set of physical and mechanical properties, what steel should be selected, and how it should be nitrided for given types of service, and finally what service performance may be expected under the wide variety of conditions imposed by industry.

In its simplest form the nitriding process consists in heating the steel parts in an atmosphere of ammonia to temperatures ranging from 850° to 1200° F., usually for one to two days. The rather long time required is the chief difficulty from the production point of view, and, of course, much effort is being put upon cutting it down. More frequently the nitriding temperature is within the range of 950° to 1000° F. For special purposes combinations of high and low temperatures are used in nitriding; for example, Sergeson[43] has proposed the use of a low nitriding temperature (950° to 1000° F.), followed by a high nitriding temperature of 1150° to 1200° F. as a means of producing a tougher case, and at the same time producing a case of greater depth in a given period of nitriding treatment.

The Nitriding Process

On the other hand, McQuaid[31] has reversed the cycle and patented (U. S. 1,804,176) a nitriding cycle in which he uses first a high nitriding temperature, such as 1200° F., and then follows this by a low temperature, such as 950° to 1000° F. McQuaid makes the claim that this cycle materially shortens the nitriding time, and yet produces a case with satisfactory properties.

Cowan has described a continuous nitriding furnace, in which the steel and ammonia flow is in the same direction, thus subjecting the steel first to the action of practically pure ammonia at a low nitriding temperature. As the work flows through the furnace, a higher temperature is reached, and the exhaust gas is 85 to 95% dissociated. This process is claimed to shorten the time required, to produce a high quality case, and to give a much better utilization of the ammonia, with a 90% dissociation, as compared with the usual 30%.

Merten[39] has recommended nitriding at 650° to 700° for 2 hours, at 850° to 900° F. for 2 hours, and then at 975° to 1000° F. until the required depth of case is obtained the depth being about 0.001 inch per hour at 975° F.

A variety of furnaces and other items of equipment have been developed for carrying out the nitriding operation.[4, 22, 39, 43] At least ten companies are manufacturing furnaces which have been especially designed for nitriding service. Modifications of the above process have been studied, in which attempts have been made to accelerate the nitriding operation by the introduction of catalyzers[29], materials to absorb the hydrogen[31], etc. Kinzel and Egan[28] have proposed a process of producing a nitrided surface on steel by heating at low temperatures, 860° F. (460° C.) in a molten cyanide bath. The process is capable of producing a high surface hardness but seems to be limited to very thin cases of the order of a few thousandths of an inch.

The nitriding process as usually carried out is capable of producing extremely high surface hardnesses (1000 to 1200 Vickers-Brinell), and cases of considerable depth can be produced, providing a sufficiently long nitriding time is used. The maximum hardness of the case results from nitriding at about 950° to 1000° F. and decreases somewhat as the temperature is increased to 1200° F. The depth of case depends both upon the time of nitriding and the temperature and increases with both of these factors. Circulation of the ammonia gas in the nitriding chamber is desirable and is provided for by mechanical means or by the proper location of the gas inlets and outlets.

Exactly why a nitrided case is hard is not known. It is generally agreed that in the nitriding process ammonia coming into contact with the surface of the steel is decomposed or dissociated into nitrogen and hydrogen, both of which exist first in the nascent state. In this condition the nitrogen reacts with the steel to form compounds of iron and certain alloying elements. The nitrogen then diffuses into the steel, the rate of diffusion being a function of time, temperature and to some extent composition of the steel.

Grossmann[11] has suggested that the hardness is due to the formation of practically non-diffusible aluminum-nitrogen compounds (aluminum being used to represent the nitrogen hardening elements chromium, molybdenum, vanadium, etc.). Hardening may be due to precipitation of fine particles of such compounds, and hence may be classed among age-hardening or precipitation hardening phenomena.

Merten[39] attributes the hardening both to formation of a hard solid solution and to precipitation, and says that the somewhat lower hardness, but greater ductility, of aluminum-

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molybdenum steels, as compared with the aluminum-chromium-molybdenum steels, is due to the fact that in the former the hardness is solution hardening entirely. However, the fact remains that the surfaces of certain steels can be made extremely hard by nitriding, and that is what the engineer wants to know, thus leaving to the metallographer the problem of sometime determining the "why."

Cost of Nitriding

The cost of producing hard, wear resistant surfaces on the steel by the nitriding process is usually compared with the cost of case carburizing and hardening. The prices of the nitriding steels range from two to three times those of the case carburizing steels, depending upon whether the latter is an alloy or plain carbon steel.

The cost of nitriding to produce a case $^1/_{32}$" in depth, as compared with producing the same depth of case by carburizing and hardening, has been estimated as ten to twenty times as great by one man engaged in commercial heat treating.[51] On the other hand, Freeland reports that the cost of nitriding is little more than carburizing and hardening, especially when the cost of straightening warped parts and the loss due to rejected parts are considered. One automotive company reported that the cost of nitriding given parts did not exceed the cost of carburizing and hardening the corresponding parts.

Installing nitriding equipment is a large item of the cost, and while nitriding furnaces can be used for drawing and some are designed for alternative use in carburizing, they usually mean additional equipment, which is chargeable to nitriding. As a result, unless the volume of work to be nitrided is large, the overhead is high. The costs of heating and for ammonia are comparatively low, one company reporting 1.6¢ and 3.7¢ per pound for nitriding 24 and 60 hours, respectively, for both of these items.[51] Quotations for commercial nitriding show a wide range, depending upon depth of case required, tolerances, amount of work, size of parts, etc.

Small experimental nitriding furnace. (Battelle Memorial Institute.)

The deciding factor in most cases will be that a nitrided part will do the job, whereas a carburized part will not, or will not do so well.

Dimensional Changes During Nitriding

Experience has shown that nitriding produces an increase in size of the hardened part. The amount of this increase or growth is dependent upon the depth of case or upon the nitriding time and temperature.

Sergeson[44] reports about 0.002" growth in diameter for a case of 0.025" depth. McQuaid and Ketcham[32] observed a growth of 0.001" in diameter for specimens nitrided 15 to 20 hours, which is in general agreement with Sergeson's data.

Fortunately, the amount of growth in a given nitriding job is a constant and can be provided for in machining before nitriding, at least in most cases. Grossmann[11] has pointed out that when a part is tinned on one side as a means of protection against nitriding, the growth on the other side is likely to cause warpage. Nitrided rings, according to Walsted,[49] will show an increase or a decrease in the internal diameter, depending upon the relative strength of the case and the core. If the core is relatively large, then the case must expand inward and therefore decreases the inside diameter. If the core is a small section, the case may expand the core, thus producing an increase in the inside diameter. Such changes may likewise cause warpage in certain complicated shapes.

Protection against Nitriding

Protection against nitriding can be obtained by nickel plating and by coating with tin or lead-tin alloys. Painting with a mixture of glycerin and tin oxide or waterglass and chrome ore has also been used. The preference seems to be for coating with tin, but care must be taken to remove excess tin; otherwise, it may melt and drop onto other parts lower in the furnace, thus causing soft spots.

Nitriding Containers

A variety of materials have been used in the construction of nitriding containers. Grossmann[11] is the authority for the statement that only two kinds of containers have been found satisfactory. One is a steel containing 25% Cr and 20% Ni, and the other is an enameled container. He reports over 2700 hours' successful use of an enameled container.

Merten[37] has expressed a preference for nickel containers, and some furnace manufacturers are using monel for containers. Sergeson and Deal have reported using monel of of low manganese content up to 1000 hours without the container showing any tendency to nitride. Sergeson and Deal[47] found that plain carbon steel and stainless iron, in longer service, nitride, and that the nitrided container catalyzes the dissociation of the ammonia on the container surface, rather than on the part to be hardened, which results in turning out a product which is low in hardness.

The nitrided surface can be removed by sand blasting or by heating to a high temperature.

Woodson[50] has discussed the materials for nitriding containers and mentions several alloys which are being used experimentally.

Nitriding Steels

The compositions of the principal nitriding steels are given in Table I. It will be noted that all of these steels contain one or more of the elements aluminum, chromium, molybdenum and vanadium. It is now considered that aluminum and chromium are most effective in contributing extreme hardness to the nitrided case, while molybdenum and vanadium increase the toughness and depth of penetration.

These nitriding steels may be divided into groups on the basis of the special alloying elements contained. Thus Nos. 1, 2 and 3 represent the Al-Cr steels, No. 4 an Al-Cr-Ni steel, Nos. 5, 6 and 7 Al-Mo steels, and Nos. 8, 9, 10 and 11 Al-Cr-Mo steels.

The other steels listed in Table I are either less common or more recently developed nitriding steels. No. 12 has been used for exhaust valves in internal combustion engines. No. 13, which has a relatively high chromium content was studied by Fry and was intended to give greater core hardness than the usual nitriding steels.

No. 14 is the type of steel proposed by Kinzel. It finds

Table I.—Compositions of Principal Nitriding Steels

No.	C	Al	Cr	Mo	Ni	Bibliography Reference
1	0.10	1.00	1.50	....	....	Homerberg and Zavarine[24]
2	0.40	0.80	1.60	....	....	Homerberg and Zavarine[24]
3	0.36	2.03	1.62	....	0.10	J. D. McAdam, Jr.[30]
4	0.30	1.30	1.60	....	1.40	Homerberg and Zavarine[24]
5	0.25/0.40	1.0	....	0.80/1.0	....	Merten[35]; McQuaid and Ketcham[33]
6	0.25	1.0 /1.4	....	0.60/1.0	....	Colonial Steel Company[2]
7	0.26/0.31	1.0 /1.2	....	0.15/0.25	....	Herbert[19]
8	0.10/0.20	0.60/1.2	0.80/1.3	0.15/0.25	*	Sergeson and Clark[46]
9	0.20/0.30	0.60/1.2	0.80/1.3	0.15/0.25	*	Sergeson and Clark[46]
10	0.30/0.40	0.60/1.2	0.80/1.3	0.15/0.25	*	Sergeson and Clark[46]
11	0.55/0.65	0.60/1.2	0.80/1.3	0.15/0.25	....	Sergeson and Clark[46]
12	0.45/0.60	0.25/1.0	7.0 /9.0	0.40/1.0	(Si 1.0/2.0)	Colwell[3]
13	0.18	....	3.00	0.40	....	Fry[9]
14	0.38	Nil	0.11	Nil	(0.48% V)	Kinzel[26, 51]
15	1.50	.....	12/14	'1.0	(1.0% V)	[51]
16	0.27	.....	1.50	.....	(0.50% V)	Kinzel[27]
17	0.37	1.06	1.07	0.19	(0.15% S)	Sergeson[45]

* Some manufacturers report about 0.50% Ni in these steels.

some commercial use where the extreme hardness obtainable with such steels as Nos. 1 to 3 is not required, but where a greater toughness of the case is desirable.

No. 15 represents a recent development in which high carbon and high chromium are used with molybdenum and vanadium. This steel was developed especially to give high hardness and high strength cores, and is unusual in that it can be so heat treated that secondary hardness is developed in the core during the nitriding process.

Steel No. 16 represents a steel used by Kinzel[27] in some of his recent researches and is of only slightly higher chromium and vanadium content than the series recently proposed by the Vanadium Corporation of America.[48]

Steel No. 17 is essentially the same as No. 10, except that it has a high sulphur content, the sulphur being introduced as a means of producing a free machining nitriding steel.

Steels Nos. 1, 2 and 3 represent the earliest developments in this country, and they have been largely replaced by steels of the type represented by Nos. 8, 9 and 10, the molybdenum having been introduced as a means of obtaining greater toughness of the nitrided case and greater depth of penetration. Some of these steels originally contained relatively high chromium—about 2%—but the chromium content has now generally been reduced, in order to give better machinability.

Steel No. 4 has probably been entirely discarded by this time, due to the fact that it was subject to temper brittleness.

Steels of the type represented by 5 and 6 are generally considered to give somewhat lower hardness than the aluminum-chromium steels but to give rather greater depth of penetration and tougher cases. Merten[38] and others have expressed a preference for steels of this type for the production of large-sized ingots, which are necessary in the production of large nitrided parts, such as Diesel engine crankshafts. Such steels are reported to give sounder ingots which are freer from segregation and, therefore, lend themselves better to the production of large parts by forging operations.

Steel No. 7 does not seem to have been used in commercial nitriding in this country, although it was used by Herbert in some of his research work, and may be used commercially in England.

Steels Nos. 8, 9 and 10 are extensively used for nitriding purposes at the present time.

Steel No. 11 is similar to those just mentioned, except that it has a higher carbon content and was developed especially for those services requiring a core of higher strength and greater hardness. The special qualities of the other steels have already been discussed.

Preparation for Nitriding

It is now quite generally recognized that steels should be heat treated in rather definite ways previous to nitriding. The writer's original purpose (1927) in introducing heat treatment previous to nitriding was to produce a core of the best possible physical properties, which was still machinable. Such a treatment obviously involved heating to a sufficiently high temperature to refine the grain size, making the steel homogeneous, followed by quenching and drawing to suitable temperature to produce satisfactory machinability. Experiments showed that such heat-treated samples also produced more satisfactory cases both as regards to hardness and depth of penetration. It has now become general practice to heat the steels first to a relatively high temperature, the exact temperature depending upon the composition, followed by quenching or air cooling, after which the steels are drawn to a temperature at least as high as the maximum temperature to be used in the nitriding.

In addition to the advantages previously mentioned, such a heat treatment leaves the steel essentially free from strain and, therefore, minimizes, or eliminates warpage during the nitriding treatment or in service after nitriding.

In addition to the proper heat treatment previous to nitriding, another precaution has been found absolutely necessary—that is, the removal of decarburized material previous to nitriding. It is now customary to use stock from which sufficient material will be machined to completely remove all decarburized surfaces. Unfortunately, the nitriding steels seem to be subject to decarburization in heat-treating operations. Jominy[25] has studied the decarburization of nitriding steels (No. 10, Table I) in comparison with plain carbon, S. A. E. 3250, 9260, 5150, 52100, 6115, 4615 and 3115, in commercial furnace atmospheres, and found that the nitriding steel decarburized at a faster rate than any of the other steels.

The ease with which the nitriding steels are decarburized gives an added reason why great precaution should be used in removing the decarburized surface before nitriding. In order to have the finished parts as free from strain as possible, the best practice is to rough machine and redraw at a temperature equal to or slightly greater than the nitriding temperature, in order to remove machining strains, and then finish-machine or grind.

Selection of a Nitriding Steel

In the selection of a nitriding steel for any given service the same principles are involved as in the selection of any other type of steel.

First, if the exact service requirements are accurately known, and if the properties of the different materials which are available are well known, a comparatively simple engineering problem is involved in selecting the best material, giving due consideration to costs of raw materials, fabrication, availability of supply and other pertinent factors.

The second method involves the use of experience with service performance or laboratory tests. If a material has been either a success or a failure in a particular service or type of service, good engineering guesses can be made and the material selected or rejected with considerable assurance. In the development and use of nitrided materials the engineer has been handicapped by lack of complete information re-

Table II.—Physical Properties of Nitriding Steels Containing Molybdenum
(Quenched and Drawn as Indicated)

Steel No.	Drawn ° F.	Strength in 1000 lbs./in.² Tensile	Yield	Elong. %/2"	R. A. %	Hardness Brinell	Impact ft.-lbs. Charpy		Izod	Bibliography Reference
1	1000	77	48	30	69	170	62		...	24
1	1200	69	50	35	75	150	72		...	24
2	1000	191	172	13	40	390	12		...	24
2	1200	148	126	18	54	320	34		...	24
3	1200	148	108	18	54	...	..		...	30
4	1000	168	150	14	45	365	14		...	24
4	1200	132	112	20	57	285	31		...	24
5	1000	161	137	18	60	340	29		...	32
6	1000	120	100	20	67	260	..		...	2
6	1200	105	85	24	73	225	..		...	2
7	930	157	134	15	..	410		(34)		21
7	1150	108	92	30	..	260		(62)		21
8	1000	111	96	20	68	*241	..		86	46
8	1200	95	75	24	73	202	..		110	46
9	1000	146	131	14	53	330	20		40	46
9	1200	122	105	18	65	255	25		75	46
10	1000	182	165	12	44	351	17		34	46
10	1200	139	121	20	58	270	30		70	46
11	1000	206	183	11	36	450	..		18	46
11	1200	159	137	16	49	330	..		40	46
12 & 13					Data not available					
14										
15					Data not available					
16					Data not available					
17					Properties compare favorably with No. 10.					45

garding the properties of nitrided parts, so that considerable difficulty was involved in using the first method, and because of the newness of this type of material, service tests were not available which covered a period of time comparable to satisfactory life performance. He has, therefore, been forced to work with insufficient data regarding physical properties and to use the results of accelerated laboratory tests, instead of service tests. Fortunately, at the present time much better data are available regarding the properties of nitrided products, including both core and the case, and the results of comparatively long time service tests are now becoming available.

Thus in the selection of a nitriding steel and in the subsequent nitriding operation, consideration must be given to the possible properties of both core and case, as well as the requirements of the particular service under consideration. It then becomes important to know what properties can be developed in the cores and cases of the different nitriding steels, how these properties may be changed by the nitriding treatment, and by service at somewhat elevated temperatures.

Properties of Heat Treated Nitriding Steels

Since, for most nitrided parts, the core constitutes the greater part of the cross-section, the properties which can be obtained by heat treating these steels are of major importance. The hard nitrided case contributes comparatively little to the tensile strength, although, as will be shown later, it may have an important influence in increasing the endurance limit.

Table II shows the properties of the steels listed in Table I, insofar as data are available. It will be observed that with a drawing temperature of 1000° F. tensile strengths ranging from 77,000 for No. 1 to 206,000 for No. 11 are available. Corresponding Brinell hardnesses are 170 and 450. When these steels are drawn at 1200° F., the tensile strength of No. 1 is 69,000, and No. 11 is 159,000, the corresponding Brinell hardnesses being 150 and 330.

While data are not available for steels Nos. 12 and 13, the composition would indicate that both of these steels are capable of producing rather high strengths and hardnesses. This is especially true of No. 12. Complete data are not available for steel No. 15, but according to the manufacturer, this steel is capable of being heat treated, so that the core hardness after nitriding at 975° F. will range from 450 to 550. Especially high hardness in the core of this steel is developed by a previous heat treatment at a high temperature followed by nitriding at about 1000° F., which develops high secondary hardness. Incidentally, the effect of volume changes in this steel during the transformation, which develops secondary hardness, needs attention. Since the secondary hardness is due to a transformation from an austenitic structure to a troostitic or to a troosto-martensitic structure, a change which involves a gamma to an alpha lattice transformation accompanied by an increase in volume, the development of strains and even warpage in complicated sections may be expected along with the secondary hardness. What part such factors will play in affecting the hard nitrided case has not been reported.

The physical properties classify the nitriding steels into groups, one extreme of which is represented by Nos. 1 and 8, which are of low carbon content, and adapt themselves to cold forming on account of their low strength, and are to be recommended for those parts which require a high surface hardness in which high core hardness and strength are not essential. The other extreme of the group would be represented by such steels as Nos. 2, 11, 12 and 15. These steels should be selected when high core hardness and strength are required. No. 15 is especially recommended for those services in which the nitrided case must be backed up by a hard core, in order to prevent "sinking" in services in which the part is subjected to extreme loads.

The data given in Table II should serve as a guide in the selection of the nitriding steel possessing certain desired core properties. Of course, case properties have to be considered, and these will be discussed later.

In addition to the properties of the steels as heat treated, consideration must be given to the effect of the long heating at the nitriding temperature on the core properties. This has been particularly important in the case of certain steels which tend to develop temper brittleness of the core in the nitriding operation.

Effect of Nitriding Temperatures on the Core Properties

The fact that the nitriding treatment requires prolonged heating at about 1000° F. followed by relatively slow cooling imposes a condition which is known to cause temper-brittleness in certain steels. Guillet[12] has investigated the effect of nitriding 90 hours at 500° C. (932° F.) on the Charpy impact properties of the core of nitrided specimens. He studied Al-Cr, Al-Cr-Ni and Al-Cr-Mo with only 0.50 to 0.62% Ni. For the 0.26/0.41% C, 0.80/0.94% Al and 1.23/1.49% Cr steels the Charpy impact was decreased from 18.0 to 8.9. For the 0.13/0.26% C, 0.93/1.11% Al, 1.73/1.98% Cr and 1.71/1.82% Ni steels the Charpy impact was decreased from 20.7 to 3.5, or over 80%. On the other hand, steels containing 0.30/0.41% C, 1.23/1.75% Al, 1.99/2.10% Cr, 0.32/0.35% Mo, with only 0.50/0.62% Ni showed practically no loss in impact toughness, the figures being 14.1 as compared to 13.8.

Likewise, Homerberg and Walsted[22] found that holding at the nitriding temperature reduced the impact resistance

of Cr-Al, and especially Cr-Al-Ni steels but had no effect on a Cr-Al-Mo steel. Nitriding standard size Charpy test bars reduced the impact resistance, due to the formation of the hard case.

Daubois[5] found that Al-Cr-Ni nitriding steels might have their impact resistance reduced from 18 to 3 kgm. by heating 40 to 90 hours at 500° C., while with an addition of 0.3% molybdenum the impact was reduced only from 18 to 12 kgm.

Hengstenberg and Mailänder[18] have studied the effect of heat treating a series of five nitriding steels and then subjecting them to 48 hours' heating at 500° C. This prolonged heating corresponds to the heating time in the nitriding operation. They found that the physical properties were not materially changed for the steels investigated. Their nickel-containing steel (2.65% Ni) showed a slight increase in strength, and an increase in the yield point of about 16%, and both the elongation and the reduction of area decreased. The impact values are not reported, but the data for strength and toughness would suggest that the impact properties might be decreased.

It, therefore, seems that, providing the drawing temperature previous to nitriding is at least as high as the nitriding temperature, there is comparatively little change in the physical properties of the core in the nitriding treatment. An exception must be made in the case of the nickel-containing steels (over about 0.50% Ni) which develop temper brittleness, and in the instance of steel No. 15, when nitrided after quenching from a high temperature which develops secondary hardness during the nitriding treatment.

Properties of Nitriding Steels at Elevated Temperatures

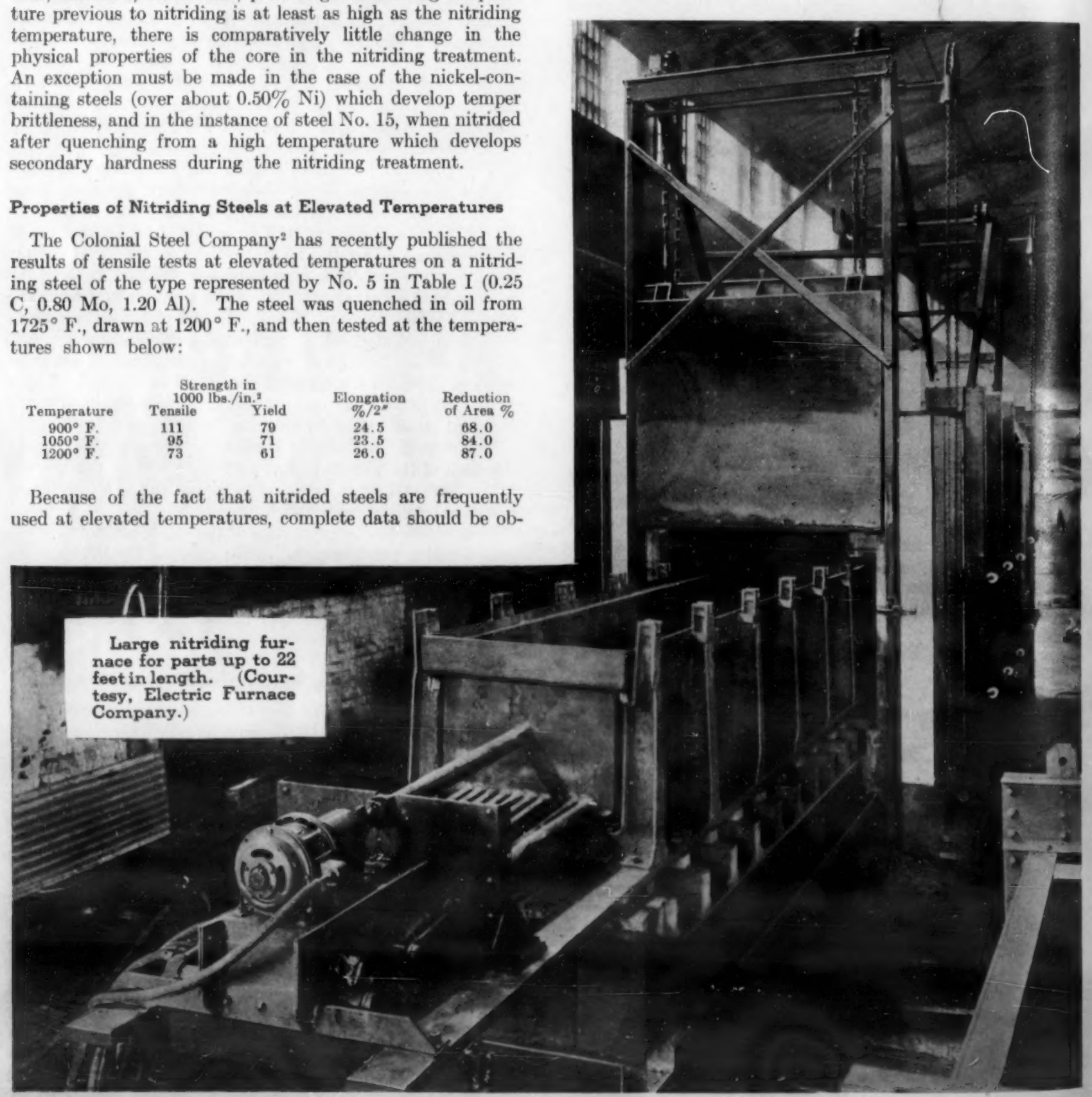
The Colonial Steel Company[2] has recently published the results of tensile tests at elevated temperatures on a nitriding steel of the type represented by No. 5 in Table I (0.25 C, 0.80 Mo, 1.20 Al). The steel was quenched in oil from 1725° F., drawn at 1200° F., and then tested at the temperatures shown below:

Temperature	Strength in 1000 lbs./in.² Tensile	Yield	Elongation %/2"	Reduction of Area %
900° F.	111	79	24.5	68.0
1050° F.	95	71	23.5	84.0
1200° F.	73	61	26.0	87.0

Because of the fact that nitrided steels are frequently used at elevated temperatures, complete data should be obtained for the high temperature, properties of all the nitriding steels, and such data should be made available to both the engineer and the metallurgist. This would seem to be a job for the manufacturers of these special steels.

Properties of Nitrided Cases

The properties of nitrided cases depend upon the kind of steel, the nitriding temperature, time, rate of ammonia flow, percent of ammonia dissociated, etc. Harder, Gow and Willey[15] have reported the hardnesses at different case depths for a series of 19 alloy steels nitrided at 1000° F. for 90 hours. The hardnesses, unfortunately, are reported in the scleroscope scale. This work indicated that the usual automotive steels were not hardened sufficiently by nitriding to make them interesting. The same authors have reported the hardness-depth curves for a Cr-Al nitriding steel and a Cr-V steel (S. A. E. 6135), which were nitrided at 875°, 975°, 1075° and 1175° F. with different percentages of ammonia dissociation. Fry[9] has reported hardness-depth curves for an 0.22 C, 1.5 Cr, 0.4 Mo, 0.35 V and for an 0.18 C, 3.0 Cr, 0.4 Mo



Large nitriding furnace for parts up to 22 feet in length. (Courtesy, Electric Furnace Company.)

steels. Similar curves for Al-Cr-Mo steels have been reported by Sergeson,[43] McQuaid and Ketcham,[32,33] Cowan,[4] Hengstenberg and Mailänder[18] and others. Similar curves for Al-Mo steels have been published by Hengstenberg and Mailänder,[18] and by McQuaid and Ketcham.[32] Only a few typical hardness-depth curves will be reproduced and discussed here.

Hardness of Nitrided Steels

Curves I and II in Fig. 1 from Sergeson's[43] researches show the hardness-depth curves for an Al-Cr-Mo nitriding steel (No. 10, Table I) nitrided 90 hours at 975° F. and a Ni-Mo carburizing steel (S. A. E. 4615), which was carburized 8 hours at 1650° F., hardened by a double quench, and tempered at 300° F., respectively. It will be noted that the nitrided case has a surface hardness of about 1100 Brinell, while the carburized, hardened and tempered steel has a maximum hardness of only about 850. Thus the nitrided case has a higher order of hardness at the surface and maintains this advantage to a sufficient depth still to present a hard wear-resistant case, even after some wear.

Sergeson[43] determined the effect of heating to different temperatures on the room temperature hardness of these two cases. He found that the nitrided case retained full hardness up to 1000° F., at which temperature the hardness of the carburized case had fallen to about 400. Thus, the nitrided case is shown to be far superior to the carburized case in retaining its hardness at elevated temperatures.

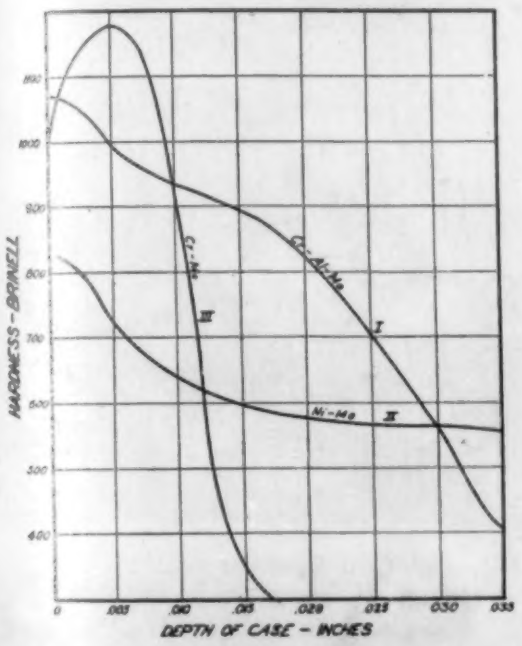


Fig. 1. Showing the hardness-depth curves for nitrided and carburized cases.[9,43]

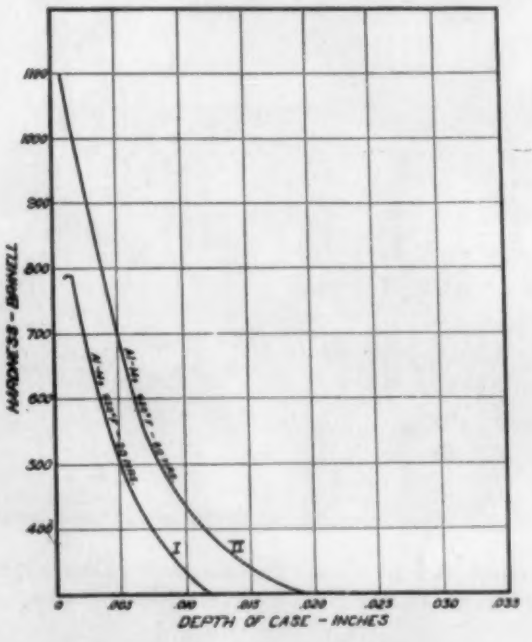


Fig. 2. Showing hardness-depth curves for nitrided aluminum-molybdenum steel.[32]

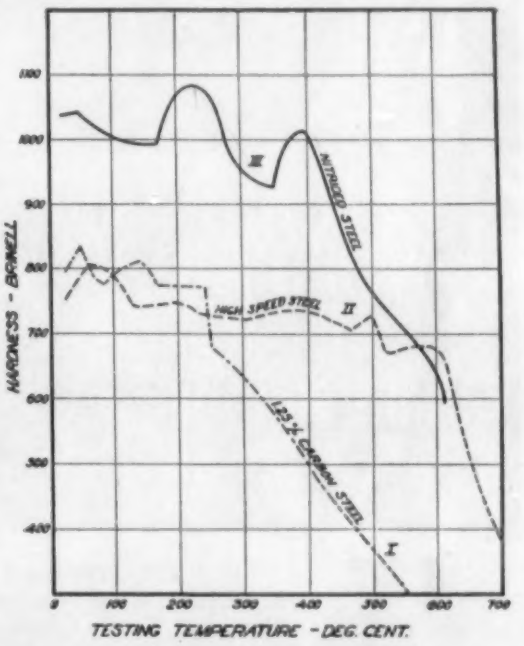


Fig. 3. Showing hardness of nitrided cases at elevated temperatures.[19]

The depth-hardness curves for the different nitriding steels, showing the effects of nitriding temperature, time of nitriding, etc., are available in many publications and are generally supplied by the steel manufacturers.

A study of the correlation of the crystal structure and the hardness of nitrided cases has been reported by Harder and Todd.[16] While such an investigation is of more interest to the metallurgist than to the engineer, it is important in showing that full hardness may be obtained in cases of nitriding steels, which show only the face-centered cubic lattice of alpha iron, thus indicating that a high nitrogen content is not essential to high hardness. The original nitrided surface was found to show those crystal structures or phases which have been shown by Hägg[13] to have high nitrogen contents, such as Fe_3N and possibly Fe_2N. Since the high nitrogen-containing constituents have been found to have rather good resistance to corrosion, but to show a tendency toward brittleness, it is immediately suggested that nitrided parts which are to resist corrosion, but which are not required to be tough, should be nitrided in such a way that a surface layer high in nitrogen is produced, and none of this surface should be removed.

It is known that short-time nitriding is being used as a means of producing a thin, hard, corrosion-resistant surface, and further developments along this line may be expected. It is entirely possible that cheaper steels can be used for such purposes.

On the other hand, it is suggested that those nitrided surfaces which are to be hard and tough should not contain the higher nitrogen-containing constituents. The selection or development of steels and nitriding processes which lend themselves to the production of such cases offer attractive subjects for further study.

It seems unlikely that maximum toughness and maximum corrosion resistance can be had with a given steel and treatment.

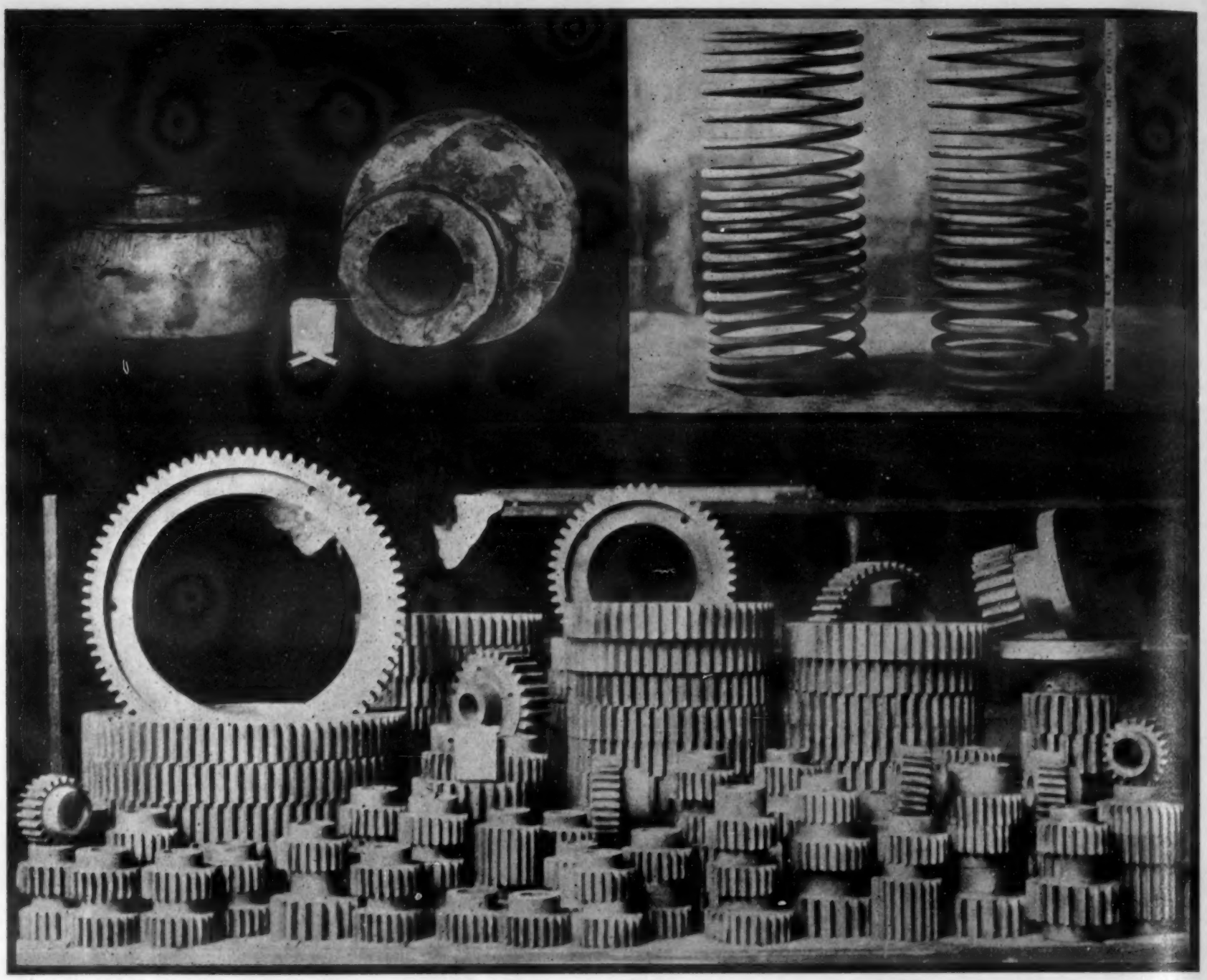
Hot-Hardness of Nitrided Cases

Herbert[19] seems to be the only investigator who has determined the hardness of nitrided cases at elevated temperatures. His curves are reproduced in Fig. 3. Curve I is for 1.25% C. steel; curve II is for a high-speed steel; and curve III is for the nitrided case of steel No. 7 in Table I. The curve of the hardness of the nitrided case shows two maxima—one at about 225° C. (400° F.), and another at about 400° C. (750° F.).

It is not necessary for our present purposes to speculate upon whether or not these wiggles in the curve are representative of other nitrided cases, or upon their cause. On the whole, it is plain that the hot-hardness does not drop notably below 400° C. (750° F.).

Above that temperature it does fall, but it is still harder than the high-speed steel at 500° C. (930° F.). The hardness at about 610° C. (1130° F.) was 600 Brinell, but after cooling to room temperature the hardness was about 900.

These data indicate that nitrided cases may be expected to retain their full hardness up to 400° C. (750° F.).



(Top left) Nitrided Cams used in Coal Breakers. (Top right) Nitrided Coil Springs for Diesel Engines. (Bottom) Three Tons of Nitrided Gears. (Courtesy, J. H. Higgins, Camden Forge Company.)

Effect of Elevated Temperatures on Room Temperature Hardness of Nitrided Cases

Numerous tests have been made in which nitrided samples have been reheated to various elevated temperatures and then tested for hardness at ordinary temperatures. Claims for no lowering of hardness after heating to 1400° F. do not seem to be justified. The writer, however, has a private communication which shows that nitrided samples of steel No. 10, Table I, have been heated 200 hours at 450° C. (840° F.) without any loss in hardness. Table III, which follows, shows the effect of reheating samples of nitrided steels on the hardness.[51] It is of interest to note that the sample of lowest initial hardness showed the lowest percent decrease in hardness at all temperatures from 1100° to 1600° F. The low original hardness and greater stability on heating suggest that this same may have been nitrided at a higher temperature. It also had a slightly higher Cr content (1.82%).

Table III.—Effect of Reheating on Hardness of Nitriding Cases

Reheating Temperature ° F.	Hardness in Percent of Hardness as Nitrided Sample No. 1	Sample No. 2	Sample No. 3	Average
1100	..	89	93	91
1200	81	82	85	83
1300	71	63	77	70
1400	57	54	70	60
1500	51	45	62	53
1600	34	....	54	44
Hardness as Nitrided	1100	990	880	Vickers-Brinell
Reheating Time, Hours	1	1	5	

Tensile Properties of Nitrided Steels

Since, as previously pointed out, the nitrided case constitutes only a minor portion of the cross-section of the tensile test specimen, it has little effect on the tensile strength. Homerberg and Walsted[22] have reported the results of an investigation in which specimens of steel No. 10 in Table I were drawn at various temperatures and then nitrided 90 hours at 900° F. Their results show that with low drawing temperatures there may be a loss in both the maximum strength and the yield point as a result of the nitriding treatment. When the specimens were drawn at 1100° to 1300° F. there was little or no change in the strength. The toughness properties, elongation, reduction of area and impact were markedly lowered in all instances by the nitriding.

Similar results were obtained by Hengstenberg and Mailänder,[18] who studied a series of five nitriding steels. Their specimens were heat treated and then nitrided 48 hours at 930° F. Some of their steels were rendered rather brittle by the nitriding treatment, as shown by the fact that the elongation and reduction of area dropped to very low values or were not determinable. Further details and discussion of these tests have been reported elsewhere.[14]

Mochel[41] has determined the tensile properties of a nitrided steel (type 10 in Table I) at elevated temperatures. He found that the tensile strength, modulus of elasticity, proportional limit, and yield point all decreased with in-

creasing temperature of testing. Tests were made up to 1050° F. The elongation and reduction of area increased with increasing temperature, except that minima in these values were found in the region of 500° F. Duplicate tests showed rather wide scattering of values.

A similar study has been reported by Homerberg and Walsted[22], in which they tested nitrided specimens of steel No. 10 at temperatures from 800° to 1400° F. Their specimens were quenched from 1650° F., drawn at 1000° F. and then nitrided 90 hours at 900° F. The strength fell off rapidly above 1000° F. and was only 20,000 lbs./in.^{2} at 1500° F. The elongation and reduction both increased to 1000° F., above which they were indefinite.

Some of the steels listed in Table I may be expected to show somewhat higher strengths at elevated temperatures than No. 10. Furthermore, it is entirely possible that some of the steels which are known to have good strengths at elevated temperatures can be hardened by nitriding. For example, some valve steels and some high speed steels respond to the nitriding treatment.

Endurance Properties

Fuller,[10] Mochel,[41] Sergeson and Clark,[46] and Hengstenberg and Mailänder[18] have all found high resistance to repeated stress in rotary bending endurance tests on nitrided steels. The nitriding steels, without nitriding, showed the usual endurance ratio; i. e., the endurance limit was about half the tensile strength. With the hard nitrided case present at the most highly stressed portion of the bar, the endurance ratios rose materially, and the endurance limits mostly ran from 75,000 to 95,000 lbs./in.^{2}

It appears that the higher strength of the case is responsible for the increased endurance limit of nitrided specimens. Hengstenberg and Mailänder[18] also determined that a slight imperfection or surface damage on nitrided specimens was not particularly harmful and, therefore, did not lower the endurance limit as in the case of ordinary heat-treated steel specimens.

One of their specimens (0.15% C, 0.85% Cr, 0.41% Mo) showed a particularly marked increase in endurance limit due to nitriding, the endurance limit being raised approximately 30%. In this specimen the maximum hardness of the case was only about 700 Brinell, but the case showed a greater depth than the other steels. The increased depth of case apparently was responsible for the higher endurance limit.

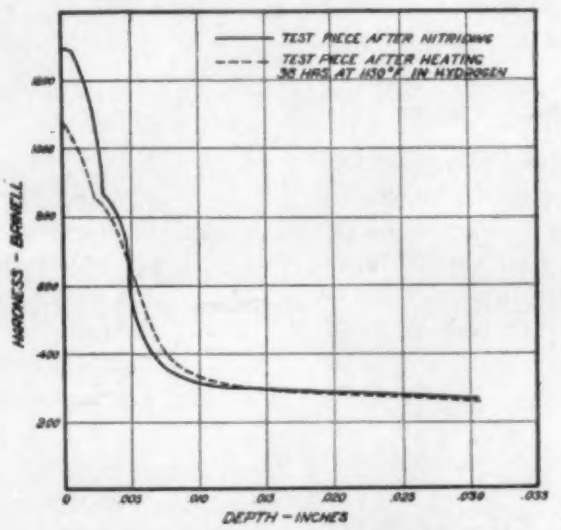


Fig. 4. Showing the hardness-depth curves for nitrided steel before and after heating in hydrogen.[4]

McAdam[30] included steel No. 3 in Table I in his researches on the influence of stress on corrosion. The properties of this steel as heat treated are given in Table II. The specimens used by McAdam were quenched in oil from 1750° F. and reheated 230 minutes at 1200° F. Specimens were ground and polished before nitriding, so that the original surface was not disturbed after nitriding.

Under the particular conditions used in his tests, the nitrided steel was found to be superior to stainless steel in resistance to fatigue corrosion. He found the nitrided steel superior in resistance to corrosion fatigue in carbonate or salt water to any other alloys investigated; these included Cr-Ni steel, Cr-V steel, stainless iron, Ni, Al-bronze, Cu-Ni-Si alloy and Muntz metal.

A few data from Fuller[10] and the other available information indicate that the endurance limit of nitrided steels may be expected to maintain its high value at elevated temperatures, even up to 800° or 1000° F., because the hardness and strength values are maintained to these temperatures, and because the endurance properties of steels are generally maintained up to temperatures at which the strength and hardness begin to fall off.

A word of caution should be added regarding the probable endurance in axial loading, in which the higher strength of the case may not be as beneficial as in rotary bending.

It should also be remembered that in practical service, where repeated stress may be accompanied by repeated impact, the results of the usual laboratory endurance test cannot always be taken as a sufficient criterion for service life. Since notched bar impact strength is reduced by nitriding and actual life in rough service is usually a sort of balance between laboratory endurance limit and notched bar impact strength, it might be a bit optimistic to quote the high figures without a word of caution.

Creep Tests on Nitrided Steel

Malcolm[34] has reported the results of a long duration test on a nitrided chromium-aluminum steel which was tested at 1000° F. under a load of 10,180 lbs./in.^{2} The extension in the first 4000 hours amounted to 0.002 in. per inch, and there was no further extension during an additional 5000 hours.

Abrasion and Wear Resistance

Malcolm[34] has reported on the scratch hardness of nitrided steels and rates it much higher than high speed steel. He also found the abrasion resistance high.

Under a pressure of 200 lbs. a stainless steel was badly abraded by 1000 revolutions in his test apparatus, while a nitrided steel in the same test under the same pressure withstood 100,000 revolutions with comparatively little wear.

Guillet[12] has studied the wear resistance of nitrided steel and cast iron automobile cylinders after 18,630 miles' travel, finding 0.016 inch wear on cast iron and 0.0008 inch on the nitrided cylinders. On aviation motors he found that heat treated steel cylinders wore 0.003 to 0.004, while the wear on nitrided cylinders was not measurable.

Homerberg and Walsted[23] have reported wear tests, in which nitrided steel was tested without lubricant against nitrided steel, a special bronze and cast iron. Nitrided steel exhibited excellent wear properties, even without lubrication. Nitrided steel against nitrided steel was carried to over 800,000 revolutions in tests at 1000° F., and showed promising possibilities.

Stability of Nitrided Cases

In the previous discussion, it has been shown that nitrided cases have been found to stand long periods of heating (200 hours) at a temperature of 450° C. (930° F.) with no loss in hardness. Also that such cases will stand heating, at least for short periods of time, to 1000° to 1100° F. with little or no loss in hardness. Cowan[4] has studied the effect of heating a nitrided steel (No. 9, Table I) for 36 hours at 1150° F. in an atmosphere of hydrogen. Fig. 4 shows the hardness-depth curve for this steel as nitrided in curve I, and after heating in hydrogen in curve II. There has been a loss in hardness, but the loss is of the order shown in Table III, and Cowan concludes that molecular hydrogen has no action on the nitrided case.

(Top left) Nitrided Disks which are used in large numbers. (Top right) Nitrided Dies through which celluloid is pressed. (Bottom) Nitrided Corrugated Paper Mill Rolls. (Courtesy, J. H. Higgins, Camden Forge Company.)

Fig. 4 also shows that there has been a penetration of the case, due to the long heating at 1150° F.

Merten[36] proposes to soften nitrided cases by a chemical decomposition of the nitrides, heating the part to be "denitrided" in a sodium and potassium chloride bath at 1450° to 1500° F. and cooling slowly. Sergeson and Deal,[47] however, have shown that the softening of the nitrided case is due essentially to the effects of temperature and time of heating. Merten claimed that "denitrided" cases could be renitrided with satisfactory results, while Sergeson and Deal found that it was necessary completely to remove the previous case before satisfactory results could be obtained by renitriding.

Sergeson and Deal[47] also found that there was migration or penetration of the nitrided case on heating to elevated temperatures, such as 1600° to 1800° F. It seems quite well established that nitrided cases can be softened by heating at sufficiently high temperatures, beginning at 1000° to 1200° F., and that the softening takes place by a scaling action at the surface and a migration of the case into the core. The scaling is undoubtedly influenced by the surrounding atmosphere, but molecular hydrogen is not particularly harmful at 1150° F.

Corrosion Resistance of Nitrided Steels

Malcolm[34] has reported that nitrided steel resists oxidation and corrosion under the action of superheated steam. Sergeson and Deal[47] have studied the corrosion resistance of a nitrided steel (No. 10, Table I), using samples which had been nitrided 90 hours at 975° F. (525° C.). The various corroding media studied and the different conditions employed are given in Table IV.

Table IV.—Corrosion Tests Reported by Sergeson and Deal[47]

Corroding Medium	Conditions of Test
20% Sulphuric Acid	Cold and 150° F.
20% Hydrochloric Acid	Cold and 150° F.
Crude Oil	Cold and 150° F.
5% Sodium Hydroxide	Cold and 150° F.
20% Sodium Chloride	Still and aerated
20% Salt Spray	.....
3% Sodium Chloride	Alternately wet and dry
3% Calcium Chloride	Still and aerated
Ethyl Gasoline	.....

As a result of their tests Sergeson and Deal drew the following conclusions:

1. Nitrided steel is not adapted for use in mineral acids, such as sulphuric and hydrochloric.
2. It is extremely resistant to alkali, atmosphere, crude oil, ethyl gasoline, natural gas combustion products, tap water and still salt water.
3. It is slightly attacked in aerated salt water and under alternate wetting with salt water and drying.
4. There seems to be no action between it and brass in contact, either still or moving, immersed in hard water.

Homerberg and Walsted[22] have reported that specimens nitrided 90 hours withstood the action of salt spray over 100 hours. It seems to be a general opinion that the original nitrided surface offers better resistance to corrosion than ground or even polished surfaces. The nitriding treatment is being applied to plain carbon steel in certain uses as a means of preventing corrosion.

Welded Nitriding Steels

Fry[9] at the Nitriding Symposium in 1929 mentioned among the unsolved problems: "Obtaining welds in which the weld junction will be perfectly hard after nitriding." Apparently[51] this problem has now been solved in the development of large cylinder bushings for locomotives which are made by forming the bushing from plates and then welding in the atomic hydrogen arc.

Soldering onto Nitriding Surfaces

It has been found that by employing the usual precautions, attachments to nitrided cases can be made by soldering with soft solder.[51]

Uses of Nitriding Steels

The use of nitrided materials in general is dependent upon a high degree of hardness and resistance to wear, abrasion, erosion; to some extent upon resistance to corrosion; and possibly to a high endurance limit when subjected to repeated bending stresses under the previously mentioned service conditions.

Many uses of nitrided parts have been published by Alden,[1] Freeland,[7] Homerberg[21] and Sergeson and Clark,[46] and by trade publications. More specialized uses have been reported by French and Herschmann,[8] Helquist,[17] Malcolm[34] and Roshong.[42]

The following are some of the automobile parts which have been made of nitrided steels: cam followers, cams, cam shafts, crank shafts, piston pins, pump shafts, push rods, seats for valves, steering worms, taper gears, tappets, timing gears, valves, valve push rod rollers, valve stem guides. According to Freeland,[7] nitrided cylinder liners have been used in the Hispaño-Suiza, which showed unusually low wear in service, and nitrided bevel and transmission gears are used in some of the best cars in France and Germany.

Of the above uses the exhaust valve presents a severe high temperature requirement. It is now generally agreed that the usual nitrided steels are attacked when used as valves with gasoline containing tetra ethyl lead, but they are reported to work well with "straight run aviation gas." Colwell[3] discusses the use of No. 10 in Table I for intake valves and steel No. 12 for exhaust valves. These valves were used in an endurance flight of 647 hours at an average speed of 1400 r. p. m. After the run the valves, stems and seats were bright and clean. It was estimated that during the run the valves opened and closed more than 27 million times, the exhaust valve temperature ranging well over 1000° F.

Thus in the absence of lead tetra ethyl and its combustion products, it seems that nitrided steel gives satisfactory valve performance. For extremely high temperatures special nitriding steels should be used in order to provide greater high temperature strength.

Mochel[40] has reported the absence of seizing in the use of nitrided steels for valve guide and valve bonnet bushings, which have to operate under high temperature conditions without lubrication. His tests were made at 750° F. He found that nitrided steel operated well against itself and against nickel bronze, chromium plating, monel metal and stainless iron.

Alden[1] has reported endurance tests on standard and nitrided crank shafts, in which the center bearing was 0.040 inch out of line with the end bearings. The standard shafts failed after 75 hours,—the nitrided shafts in about 1500 hours. These tests indicate the durability of nitrided crank shafts in severe service. Likewise, the success of the nitrided cam shaft seems to be established.

As regards gears, there seems to be no difficulty with mesh gears but some question about clash gears, although such gears are in use. The introduction of nitriding steel of greater core strength may solve the problem with clash gears where greater tooth strength is required.

In airplane motors the uses are similar to those in the automobile. Reduction gears nitrided 80 hours at 1000° F. to give a case hardness of 950 to 1000 and a case depth of about 0.030 inch are reported[51] to be giving satisfactory service against carburized steel at about 300° F. Piston pins and cam followers nitrided 25 hours at 1000° F. are reported to be giving good service.

Alden[1] has reported the use of nitrided alloy steel in Diesel engines and listed the following parts: fuel-valve tappets and guides, pump plungers and cylinders, fuel-pump regulators, by-pass-valves and guides, valve stems, valves and seats, piston pins,* piston rods, gears, fuel injection nozzles, crank shafts, cylinder liners, fuel-nozzle spray tips, fuel-nozzle check valves and cams. The same author reports a nitrided Diesel engine piston rod 14 ft. long, $6^1/_4$ in. in diameter, and weighing about 1400 lbs., which warped only 0.020 in. in nitriding.

The use of nitrided steels for the trim on valves subjected to high temperature and high steam pressure service has been reported by Malcolm[34] and others.[51] Malcolm found that a nitrided steel possessed properties of extreme hardness, wear and abrasion resistance, chemical stability under superheated steam, combined with a tough core having high impact value and tensile strength, together with a coefficient of expansion similar to ordinary steels. His long-time loading tests and abrasion tests have been mentioned. By practical tests he found nitrided valve trim superior to either Monel or stainless steel. As an illustration, an overload valve in a large steam station was trimmed with hardened stainless steel, which failed in ten days and was replaced by nitrided steel, which after a year was functioning satisfactorily.

Nitrided gate valves were used on the 1400-pound steam pressure stations. Valve installations of nitrided steel were found satisfactory at operating temperatures of 930° to 1000° F.

Malcolm[34] also reported the replacement of the seats and disks in valves in the oil refining industry with nitrided steel which had been in service for a year without failure, whereas other materials had failed in about two weeks.

A manufacturer[51] reports that nitrided seat rings and disk rings in a line of cast steel valves for 400, 600, 900 and 1350 lbs. working pressure are proving quite satisfactory. A pressure of 1350 lbs. corresponds to a temperature of about 585° F.

Nitrided plungers for pumps in the petroleum industry are reported[51] to be working satisfactorily with "sweet" oil at 750° F. and 900 lbs./in.^{2} pressure. The nitrided plunger is said to resist the scoring and abrasive action of the packing better than any material tried so far. The nitrided plunger is not satisfactory in contact with "sour" oil.

Nitrided sleeves on boiler-feed pump shafts operating at 400° and 1700 lbs./in.^{2} pressure are reported[51] to be giving good service. In this case the nitrided sleeve is required to resist erosion due to steam leakage.

Roshong[42, 51] found that a core which had been nitrided 50 hours and used in a die casting machine in which an Al-Si alloy at 1150° F. was shot into the die was "file hard" after about two years and after producing over 125,000 castings. Helquist[17] has also reported that nitrided steel dies are useful in the production of aluminum die castings.

Higgins[20] has reported on nitriding large forgings which included plain and corrugated paper rolls from 8 to 12 inches in diameter and 108 to 144 inches in length, locomotive piston rods, engraving rolls weighing 600 to 1000 lbs., Diesel engine piston rods, and others. To this list of large nitrided parts Sergeson[44] has added large locomotive crosshead guides and heavy machine parts, weighing as much as 1600 lbs. Merten[38] has reported the production of a nitrided crank shaft for a large locomotive.

Sergeson and Clark[46] have mentioned still other uses of nitrided parts, including meat-cutter disks, movietone camera parts, forging die inserts, refrigerator valves, clay forming dies, etc.

The Firth-Sterling Steel Company[6] recommends steel No. 15, in Table I, for the following uses which have not been mentioned: ball and roller bearings, ball cones and races, dies, such as coining, wire drawing, extruding hot and cold forming, upsetting and heading, gages, sand blast nozzles, etc.

Grossmann[11] has cautioned against certain uses of nitrided parts in contact with mineral acid, under certain types of abrasion and under heavy loads.

At the present time the successful use of nitrided parts for certain services are quite well established; other applications are still in the experimental state, and some have been excluded as unsatisfactory with the usual nitrided products.

Other uses for nitriding will be found, and new steels and new nitriding practices may be expected to extend the use of nitriding to parts which are now considered unsatisfactory.

* Reports have been received that nitrided automobile piston pins are attacked by the products of combustion of tetra ethyl lead, while others report no attack after one to two years.

Regarding the future of nitriding, we may quote from Higgins:[20] "The possible uses of nitrided steels are limited only by the boldness of the designer and the vividness of his imagination."

Along with such boldness and imagination must go sound engineering principles and economic considerations.

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A "Seal of Quality," to be stenciled on galvanized sheets carrying specified weights of zinc coating, has been adopted by the American Zinc Institute, Inc., to be used by manufacturers of galvanized sheets to indicate sheets of certified quality.

A great deal has been said about the nature of the base metal used for galvanized sheets, which may be Bessemer or open hearth steel, copper-bearing steel, pure iron, copper iron, wrought iron, etc.; and the relative rates of rusting of these materials when exposed in an uncoated state have been fairly well brought out by numerous tests. A galvanized sheet, however, is a sheet of one of these materials coated with zinc to protect it from rust, and the degree of this protection is dependent primarily upon the weight of the zinc coating.

Because of the variation in the zinc coatings on commercial galvanized sheets to-day, and the lack of any means whereby the consumer may identify an adequately coated product, the "Zinc Institute Seal of Quality" has been suggested by both producing and consuming interests. Sheets bearing this seal will carry weights of zinc coating which were decided upon after careful field studies as being most suitable for the service desired.

For use in rural communities, particularly for roofing and siding of farm buildings, such sheets will be produced in No. 28 and No. 26 gage, with a coating of 1.75 oz. of zinc/ft.^{2} This coating is fully 40 to 100% heavier than coatings on most of the commercial sheets produced to-day, and will preserve the sheets from rust for a far longer period than the thinner coatings. For use in localities where atmospheric conditions are more severe, sheets of 26 gage and heavier, carrying 2.00 to 2.50 oz. zinc/ft.^{2} will be produced.

These heavily coated sheets will be sold mainly in the corrugated and V-crimp types, for use in roofing, siding and similar applications. Such sheets should not be subjected to severe bending or extreme forming operations unless special measures are taken to prevent damage to the coating.

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It has been announced that Dr. **Walter Rosenhain**, formerly in charge of metallurgical work at the National Physical Laboratory, England, has resigned.

Professor **C. H. Desch**, formerly Professor of Metallurgy at the University of Sheffield, has been appointed Superintendent of the Metallurgical Department of the National Physical Laboratory, England, and will take up his new duties in February 1932 on his return from the United States.

The American metallurgists who have had the pleasure of meeting and hearing Professor Desch on his visits to this country, congratulate the N. P. L. on its good fortune in securing a man of Professor Desch's personality and scientific ability to head up the metallurgical work.

Professor Cecil H. Desch of the University of Sheffield, England, will be Non-Resident Lecturer at Cornell University, Ithaca, N. Y. during the fall term. He will give a course of lectures covering the cohesion of solids, surface properties of crystals, influence of adsorption on growth, etch figures, chemical changes in solids and chemical properties of open-packed structures. During the same term, **Professor F. H. Rhodes** will give a course on metallurgy and properties of metals, and **Professor C. W. Mason**, one on metallography, especially aimed to supplement these lectures.

MALLEABLE IRON— Recent Progress

BY H. A. SCHWARTZ*

IN OUR interest in new alloys and new methods of heat-treatment, metallurgists and users of metals may fail to pay due attention to the older products that have served for many years. Malleable is one of our oldest heat-treated products. While the use of alloy malleable has not yet come, malleable makers have not been idle. Using the same old composition but greater care, they have steadily improved the quality and uniformity of their product.

This resume, by a member of METALS & ALLOYS' Editorial Advisory Board, a foremost authority on malleable, describes the situation as to properties and engineering usefulness of an old standby among ferrous materials.

SOMETHING over 200 years ago the development of malleable iron began something with an attempt to combine the ductility of soft iron forgings with the ease of manufacture of cast iron. It has now become an economical and dependable material of engineering construction, especially where great machinability, fair strength and good ductility are requisite. The country's annual capacity is something over a million tons which is produced by about 150 manufacturers of consequence.

The processes of molding employed are very similar to those used in the gray iron foundry except that because in the as-cast condition malleable iron is entirely white and free from graphite, difficulties from shrinkage, porosity and cracking both in cooling and handling are somewhat greater and require corresponding precautions in pattern, design, gating and feeding. The mere fact that malleable iron is made by processes which resemble those of gray iron manufacture occasionally leads to confusion in that some users have the idea that malleable iron is merely a gray iron with possibly some subsequent heat treatment; this is by no means true, the metallurgy of the two products being radically different. The graphite of gray iron is precipitated during the freezing process in the form of flaky plates of free carbon somewhat resembling fish scales. The complete precipitation of carbon as graphite in gray iron is unusual and indeed generally not desired. The graphite flakes of gray iron act as internal notches practically destroying the ductility of the material and very greatly reducing its impact resistance. These factors are further reduced by the combined carbon retained in the gray iron in the interest of adequate strength to balance the interruption of continuity of the metal caused by the flaky carbon distribution.

The finished malleable casting is a mass of carbon free iron through which graphite is scattered in nodular masses. These rounded particles do not act as notches and do not disrupt the metal as much, weight for weight, as would flakes. This particular condition is produced in the malleable casting by causing it to freeze without the crystallization of any graphite and then letting the graphite separate out at temperatures so low that flaky crystals cannot form because of the rigidity of the metal within which the crystals are growing. In the words of the metallographer the carbon nodules of malleable iron are allotriomorphic crystals; those of gray iron are idiomorphic. These formidable terms mean that in the first case the shape of the mass is imposed upon it by its surroundings, in the latter case the shape is that natural to its method of crystallization.

In order that malleable iron may successfully be made the composition of the casting must be such that it will be graphite-free as it freezes in the mold. It is also necessary that the composition be such that out of this white iron casting the carbon will precipitate in a reasonable time at reasonable temperatures. In other words, the iron must not graphitize easily but still must not be ungraphitizable and this imposes on the manufacturer a rather narrow range of composition within which he must work.

It will be quite obvious that the physical properties of malleable will depend greatly upon the amount of carbon it contains in the free state; its melting point and fluidity also depend upon carbon content, the higher the carbon the less the foundry difficulties and the less the strength and ductility. Some persons feel as the result of experience that the greater the carbon within reason the better the machinability; others are of contrary opinion but in any event the matter may be dismissed here with the statement that irrespective of carbon, malleable iron is the most machinable commercial ferrous material. The malleable manufacturer is thus confronted with the desire of not using too much carbon in order to maintain the strength and not using too little in order not to increase his foundry difficulties. Depending upon the intended use of the product he selects a range which offers the best compromise; this may be a carbon content between 2.00 and 2.20% where strength and ductility are a major consideration, a range from 2.30 to 2.60% for a fair combination of all the desired properties or a range from 2.80 to 3.00% where the prevention of foundry difficulties is a major item. Some automotive manufacturers prefer moderately high carbon contents as the most economical from all aspects.

If the metal contained nothing but carbon and iron it would not be capable of annealing in any reasonable period of time. It invariably contains also silicon and this element must be adjusted so as to facilitate the formation of graphite in anneal without causing the precipitation of graphite during freezing. The latter involves the freezing rate and hence depends upon the size of the casting so that silicon content must be adjusted from the viewpoint both of carbon content and of size of casting. In general the silicon is higher with low carbon and with thin sections than under the reverse conditions. The low carbon iron previously referred to may have a silicon content of 1% or even over especially if the sections are not too thick. The intermediate range of carbon usually involves a silicon content around 0.80 or 0.90 while the higher carbons, unless they are to be used in castings of very small section, might require a silicon content of about 0.70.

A commercial malleable casting also contains a variety of other elements which generally are present unavoidably and not on purpose. They might as well be absent if that were possible, but failing that, are kept within such limits as to remain neutral with respect to the rest of the operation; this means the exclusion of some elements which stop graphiti-

* National Malleable & Steel Castings Co., Cleveland, O.

zation, such as chromium and the balancing of sulphur and manganese against each other as manganese sulphide, which is approximately neutral. Curiously enough, it has been found that it is actually disadvantageous to make metal very low in sulphur on account of difficulties with regard to the formation of graphite during freezing.

It should be repeated that the casting as it comes from the mold is graphite free, quite hard, sometimes it will scratch glass if the carbon is high and the cooling fast, but if the carbon be low and cooling slow, it can be filed to some extent. It is absolutely brittle, not deformed at all when attempts are made to bend it, and its tensile strength is not well known because of the practical impossibility of breaking it without subjecting the specimen to cross bending loads. A material of this kind has a few commercial uses; such for example as the balls of grinding mills.

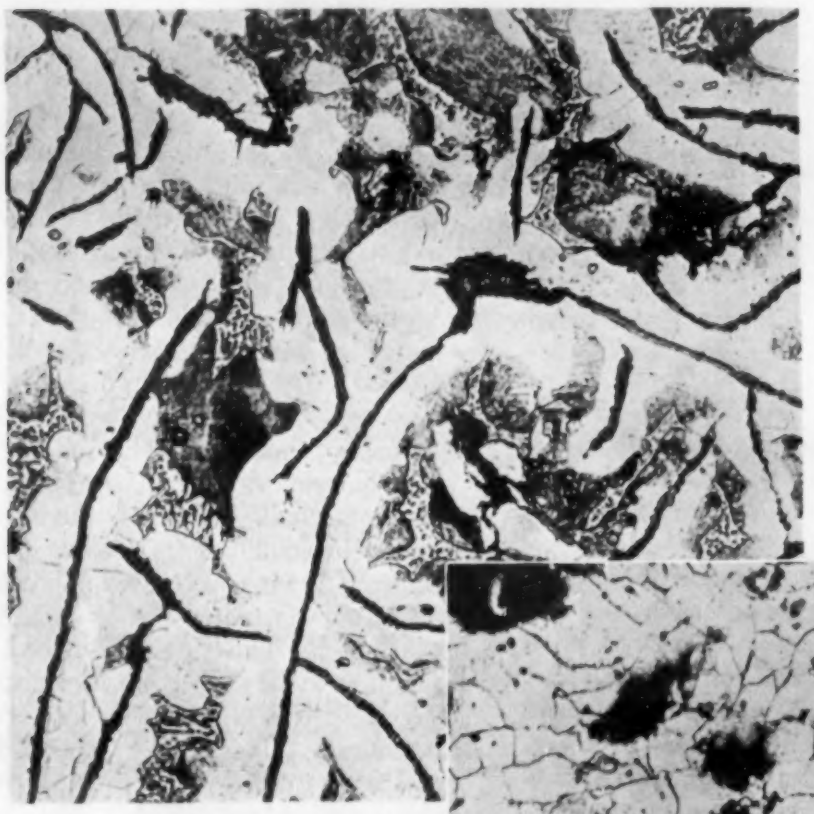


Fig. 1. Structure of hard iron before the anneal. Nitric acid etch. 200×.

It is converted into the tough, ductile, machinable product of commerce by suitable heat treatment. There seems to be no doubt that except for the hardening of tools and weapons, malleable castings were the first articles to be heat treated at all and also the first to which microscopy was applied. References exist in the literature to the effect that Réaumur in 1722 had recognized the formation of free carbon microscopically. The required heat treatments are quite prolonged, partly because of the time required for the graphitizing reaction and partly because of the time needed to distribute heat through the content of large furnaces which may readily contain fifty tons of castings and an equal weight of containers. In general the heating is as rapid as possible with the desired degree of uniformity and may occupy perhaps two days. The maximum temperature used represents a compromise between the desire to obtain speed and the desire to prevent warpage of castings under their own weight and rapid destruction of pots. It ranges in practice from 1500° to 1800° F. and is generally around 1600° F. The time required depends not only on the temperature but on the silicon content and on the other circumstances. It may be commercially anything from 10 to around 60 hours in the range of maximum temperature.

Graphitization cannot be completed above the critical point so that after the requisite time at high temperature the furnace is cooled to below the critical point, say, to 1300° F., and is maintained there until the reaction is complete. This may be done either by holding the temperature at a fairly constant point or by cooling at such a rate that the metal is in the desired temperature range for the required time which is perhaps 24 to 30 hours.

Various methods have been tried for reducing the annealing time; the continuous kiln makes it possible to heat much more rapidly and to take out the work without letting the whole furnace cool down; perhaps two days can be saved in this manner. Electrically heated inverted box type furnaces have been designed, of relatively small capacity, which can be charged and discharged without cooling and which by dispensing with the heavy pots usually used to contain castings while being annealed, economize both in heat and in time to heat uniformly. An over-all annealing time in such furnaces has been claimed to be as low as 32 hours and is frequently between 3 and 4 days as compared with a continuous kiln time of 4 to 5 days and a batch type furnace time of about a week. Furnaces of this electric type have, however, not yet come largely into use; no doubt partly because of the cost of electrical energy and the first cost of the units.

The earlier portion of the development of the metallurgy of malleable cast iron is somewhat difficult to trace owing to the absence

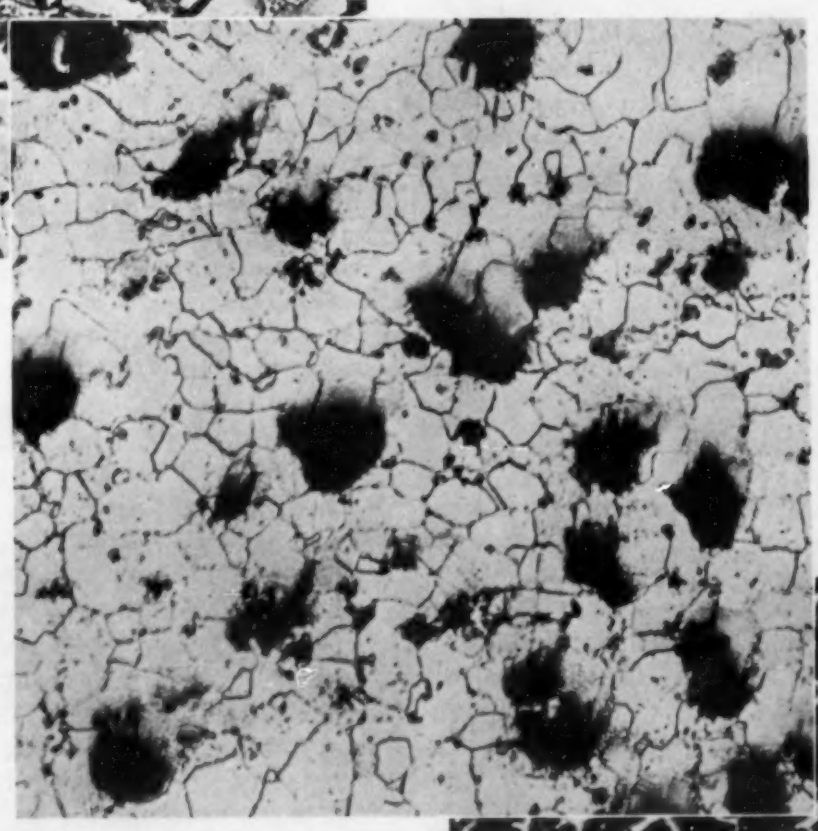


Fig. 2. Structure of malleable iron after the anneal. Nitric acid etch. 200×.

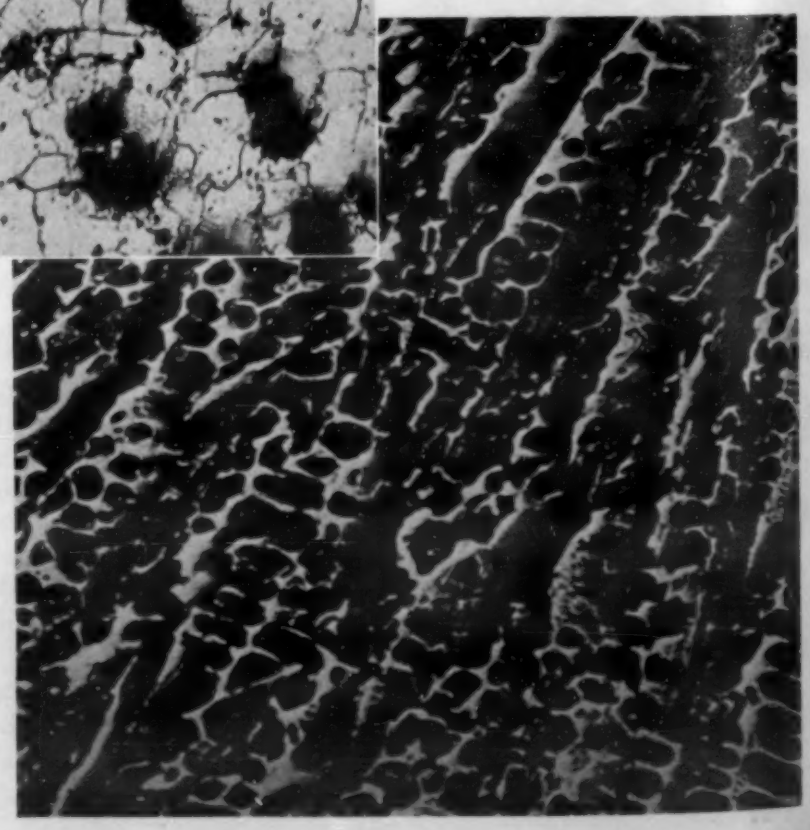
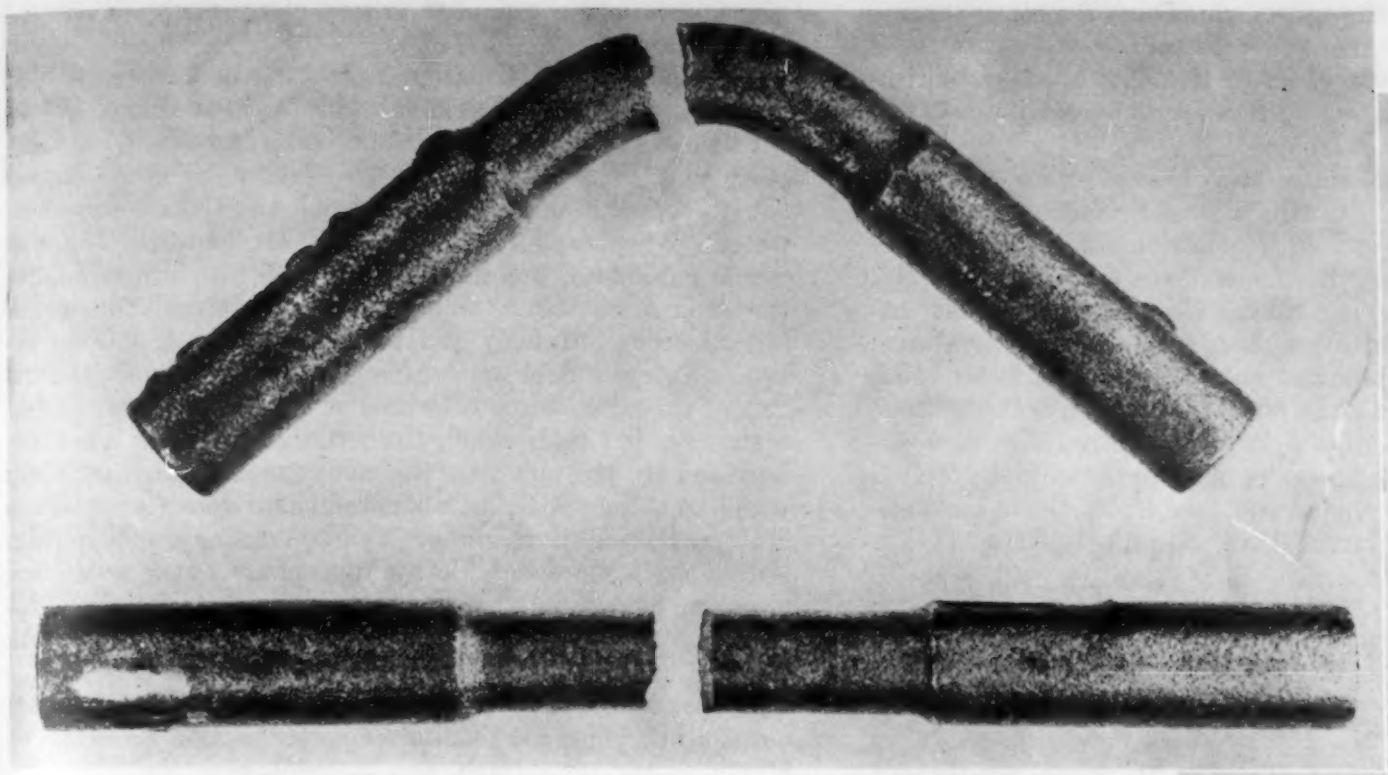


Fig. 3. Structure of soft gray iron. Picric acid etch. 200×. Note the difference in structure between this gray iron and the malleable Fig. 2.



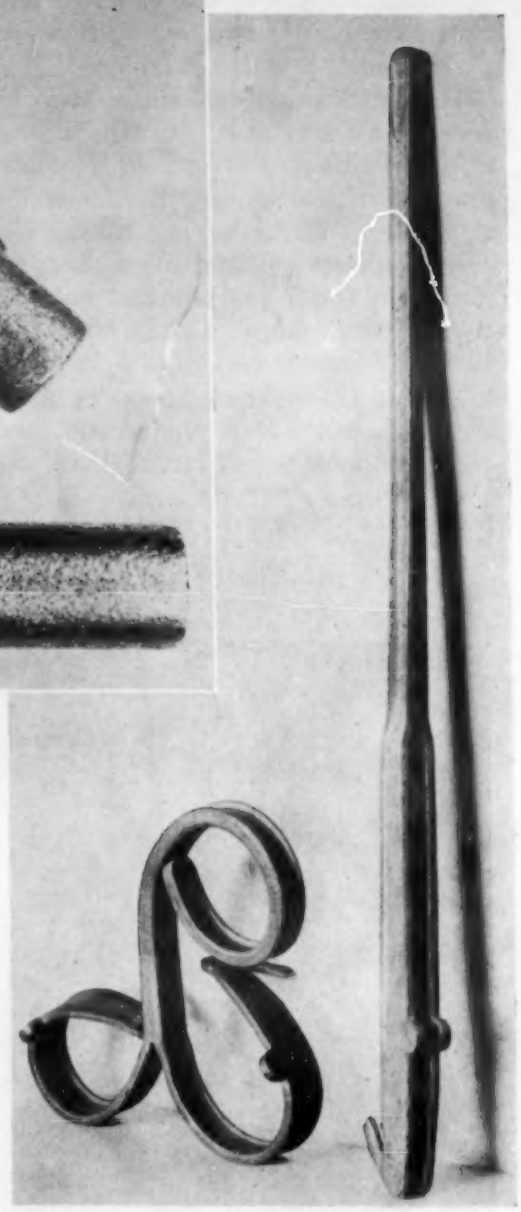


Fig. 4. What the annealing process accomplishes. Below, test bar of hard iron, before annealing, broken in cross bending, showing brittleness. Above, same annealed, showing high ductility.

Fig. 5. The toughness of malleable is shown by the way this casting may be bent without fracture.

of published results. The present writer[1] has elsewhere attempted to give some historic picture of the first two hundred years' progress, much of which need not be repeated here.

Schüz and Stotz[2] have since dealt with the subject with special emphasis upon the early history of the "white heart" process.

The original industry as founded by Réaumur was based on the partial or complete decarburization of white cast iron by heating in hematite. Boyden in 1825, first observed the ductility of material produced by allowing free carbon to crystallize from initially white, high carbon iron at temperatures defined as approximating the melting point of silver.

This form of carbon was originally believed to differ from natural graphite or the graphite of gray iron and called "temper carbon" by Ledebur. It was generally believed to be amorphous but recent investigations by Northcott,[3] Wever,[4] and perhaps others, more recently proved the identity of all three forms which are now believed to differ only in their external form.

Further, Fisher[5] showed that this external form of distribution was in large measure related to temperature of precipitation. The present writer[1] showed photo-micrographs of graphite crystallized in white iron near the solidus in which the flakes are exactly similar to some forms occurring in gray iron.

The manufacture of "white heart" iron of the decarburized type, never prevalent in the United States, has now become obsolete to the extent that malleable cast iron in this country is synonymous with "black heart" malleable. In Europe on the contrary, the white heart process predominates although the black heart is making considerable inroads. The distinction between the two continents is important for much European literature written from the white heart viewpoint is but slightly applicable to the American product although both are called by the same name.

Much information as to the relation of chemical composition to physical properties must have been gathered in the interval from, say, 1890 to 1910, but no publications were made.

[1] H. A. Schwartz. American Malleable Cast Iron. Penton Publishing Co., Cleveland, 1922.
[2] E. Schüz and R. Stotz. Der Temperguss. Julius Springer Verlag, Berlin, 1930.
[3] L. Northcott. A Note on Temper Carbon. *Journal of the Iron and Steel Institute*, Vol. 107, Part I, 1923, pages 491–494.
[4] F. Wever. Ueber die Natur von Graphit und Temperkohl. *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf*, Vol. 4, 1922, pages 81–86.
[5] E. J. P. Fisher. Relation of Temperature to Form and Character of Graphite Particles in the Graphitization of White Cast Iron. *Transactions of the American Foundrymen's Association*, Vol. 30, 1923, pages 395–419.

Moldenke[6] still recommended that malleable cast iron be not lower than 2.75% in total carbon. The writer was told in 1902 by leaders in the industry that the carbon content bore no relation to the physical properties of the metal but showed privately in 1904, that it was the predominating factor. The fact was independently observed by others, but in no case was publication made.

In 1918 the writer[7] showed a three-dimensional model giving as accurately as was then possible, on a basis of some 11,000 heats, the relation between tensile strength, carbon content and silicon content. Later,[1] a somewhat more reliable curve for the carbon-tensile strength relation at constant silicon was published.

The problem was further studied three years ago by the Malleable Iron Research Institute and permission has just been given for a future publication.

The effect of other elements upon the physical properties of malleable is somewhat obscured by the predominance of carbon and by the fact that only a limited amount of most other elements can be introduced without disturbances of the graphitizing conditions. Such information as may have been gathered has not generally been published or, so far as is known, introduced into practice for the improvement of the product. There is reason to believe that an improvement of 10% or more in physical properties can be had by such means if the inducement were sufficient.

[6] R. Moldenke. The Production of Malleable Castings. Penton Publishing Co., Cleveland, 1911.
[7] H. A Schwartz. Malleable Iron as a Material for Engineering Construction. *Transactions of the American Foundrymen's Association*, Vol. 20, 1918, page 373.

Hruska[8] discusses the use of aluminum for strengthening the product.

Formal studies of the effect of elements upon graphitization have been published by Sawamura,[9] by Kikuta,[10] and by the author with Guiler.[11,12,13]

Hayes[14] discloses formulae for the requisite annealing time as a function of Si, Mn, P and S content above the critical point and of carbon in addition for completion below the critical point. His conclusions seem qualitatively, at least, to be similar to Kikuta's. According to his disclosure silicon accelerates graphitization at all temperatures; phosphorus accelerates about one-half as much as an equal percent of silicon above the critical point and retards about as much as an equivalent of silicon accelerates below the critical point. Manganese, in excess of twice the sulphur, retards about one-tenth as fast as silicon accelerates above the critical point and retards more than silicon accelerates, below. The conclusions are limited to iron of reasonably restricted composition.

[8] J. H. Hruska. Aluminum Improves Malleable Cast Iron Properties. *The Foundry*, Vol. 59, 1931, pages 70–71.

[9] Sawamura. Influence of the Various Elements on the Graphitization in Cast Iron. *Memoirs of the College of Engineering, Kyoto Imperial University*, Vol. 4, No. 4, 1926.

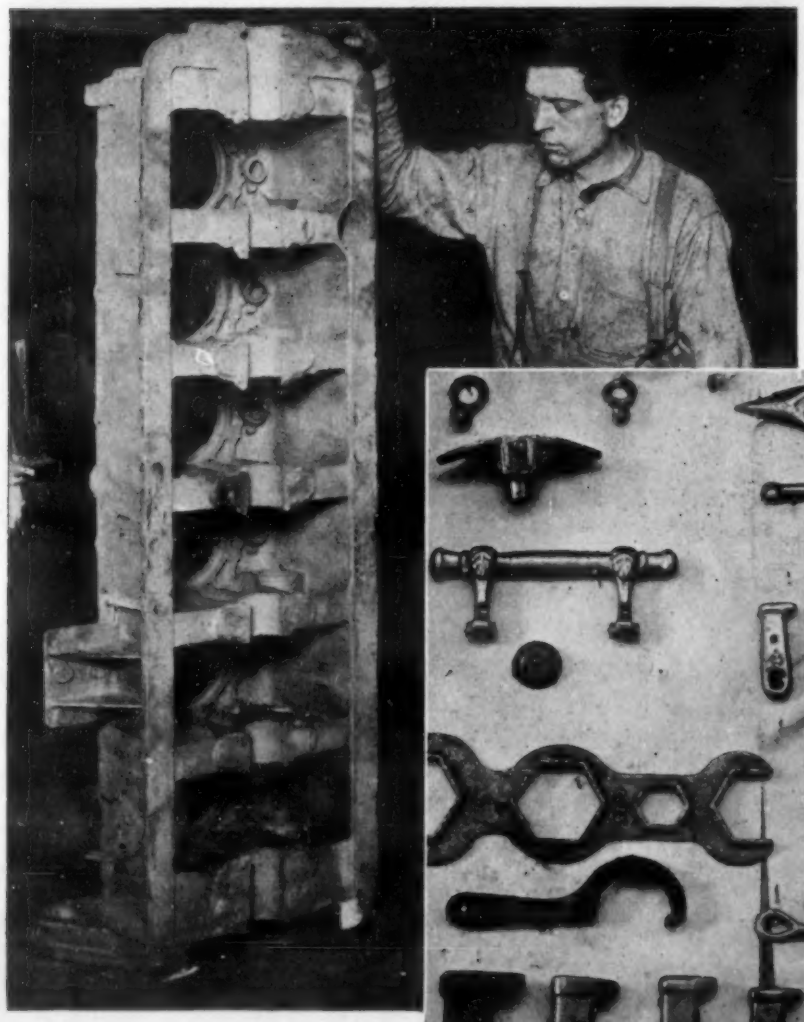


Fig. 6. Crankcase for fire engine. Length of casting 5 ft. 6 in., weight 650 lbs. Courtesy Malleable Iron Research Institute.

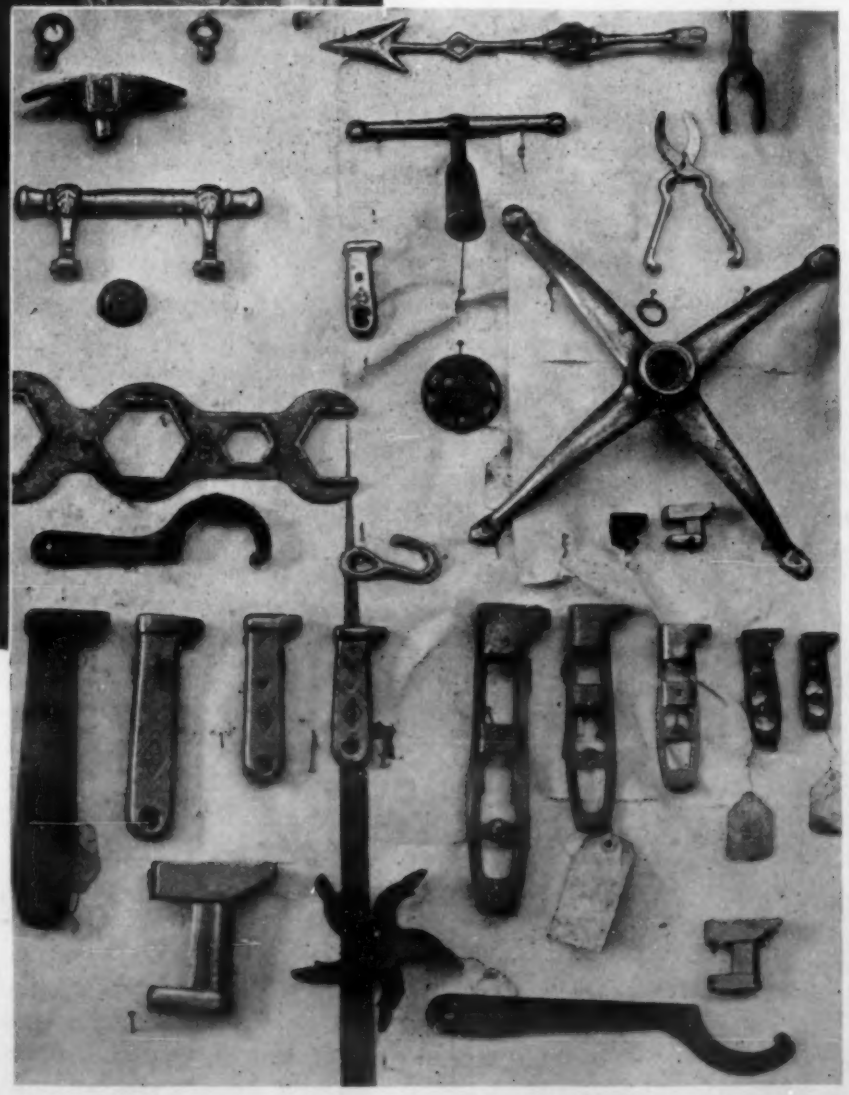


Fig. 7. Miscellaneous castings. Courtesy Malleable Iron Research Institute.

The available information may be summarized to the effect that aluminum, zirconium, uranium, titanium, nickel, cobalt, copper, gold, silicon and boron (in small amounts only) are accelerators of graphitization. The effects of cobalt, copper and antimony are small and there is some evidence that phosphorus may be an accelerator. The elements chromium, manganese, vanadium, sulphur, selenium, tellurium, boron after the first 0.10% or so, molybdenum in fair amounts, antimony and tin are retarders of graphitization. Except for chromium, manganese, vanadium and antimony, the mechanism of whose effect on the graphitizing reaction is not understood, the retarding elements are characterized by the fact that the compounds which they form with iron or the constituents of normal hard irons are present as films preventing the migration of carbon during graphitization. Such films are preventable by appropriate changes of composition, Schwartz,[15] by the introduction of elements preventing the formation of film forming compounds. Cerium and lanthanum, by forming globular sulphide (selenide or telluride) thus undo the harm occasioned by these elements although they are not themselves graphitization accelerators. The retarder, manganese, can combine with the retarders, sulphur, selenium and tellurium, rendering both itself and them harmless. The behavior of manganese and sulphur has long been known but discussed recently by Hayes and Flanders.[16]

Very generally, the cumulative effect of several retarders and accelerators all present at once is not the mere sum of the several effects. Thus in addition to the cases just cited, small amounts of nickel neutralize normal amounts of silicon; Schwartz.[17]

Also the effect of a given element is not always the same at all temperature ranges. Thus Kikuta,[10] as well as Hayes,[16] found manganese to be much more active at low than at high temperatures.

Graphitizing rates are also affected by the surrounding media, Hayes and Scott,[18] showed that mixtures of CO and CO_2 at elevated pressures accelerated graphitization above A_1, but almost prevented it below that point.

The effect of oxygen and oxidizing gases is somewhat complex. Thus Matsubara,[19] showed gas equilibrium curves demonstrating the stability of Fe_3C toward C, a result con-

[10] T. Kikuta. On the Malleable Cast-Iron and the Mechanism of Its Graphitisation. *Science Reports of the Tôhoku Imperial University*, Vol. 15, No. 2, 1926, pages 115–155.

[11] H. A. Schwartz and G. M. Guiler. Chemical Elements Inhibiting Graphitisation. *Transactions of the American Foundrymen's Association*, Vol 33, 1925, pages 639–645.

[12] U. S. Pat. No. 1,640,674, Aug. 1927. Making Malleable Iron Castings.

[13] U. S. Pat. No. 1,636,657, July 1927. Making Malleable Iron Castings.

[14] U. S. Pat. No. 1,801,742.

[15] U. S Pat. No. 1,660,398.

[16] A. Hayes and H. E. Flanders. One of the Causes of Variations in Rates of Graphitization of White Cast Iron. *Transactions of the American Foundrymen's Association*, Vol. 33, 1925, pages 634–638.

[17] H. A. Schwartz. Graphitization in the Presence of Nickel. *Transactions of the American Society for Steel Treating*, Vol. 15, 1920, pages 957–966; discussion, pages 967–970.

[18] A. Hayes and G. C. Scott. The Catalysis of the Graphitization of White Cast Iron by the Use of Carbon Monoxide-Carbon Dioxide Mixtures when Applied under Pressure. *Transactions of the American Foundrymen's Association*, Vol. 33, 1925, pages 574–593; discussion and author's reply, pages 594–609.

[19] A. Matsubara. Chemical Equilibrium between Iron, Carbon and Oxygen. *Transactions of the American Institute of Mining and Metallurgical Engineers*, Vol. 67, 1922, pages 3–55.

firmed by Schenck,[20] who, however, later showed that the equilibrium involved oxygen content in the solid phase.

Storey[21] seems to have been the first to publish data as to the mechanism of the annealing process, pointing out the elimination of Fe_3C at high temperatures and the graphitization of eutectoid cementite below A_1. The writer and his co-workers[22,23] dealt at some length with the mechanism of graphitization, developing the thought that the direct decomposition of Fe_3C with its elements does not usually occur, but that the process is one of solution of cementite, decomposition, migration and crystallization. The evidence pointed to the migratory rate as the determining factor in graphitizing rate.

Phillips and Davenport[27] pointed to a similar phenomenon, in connection with fluctuations above the critical point.

Masakichi Kubo[28] claims an acceleration of graphitization in metal carrying fairly heavy A. C. currents of a density of the order of magnitude of 100 amp./cm.^{2} The observations were not confirmed by others who studied the problem.

Saito and Sawamura[29] and the writer[30] found that white iron cooled very rapidly from well above A_1 to below that point, had its graphitizing rate enormously accelerated.

Williams[31] found very rapid graphitization in metal of abnormally high silicon content, perhaps twice usual amounts, which was kept white by being cast in a permanent mold or other chilling device.

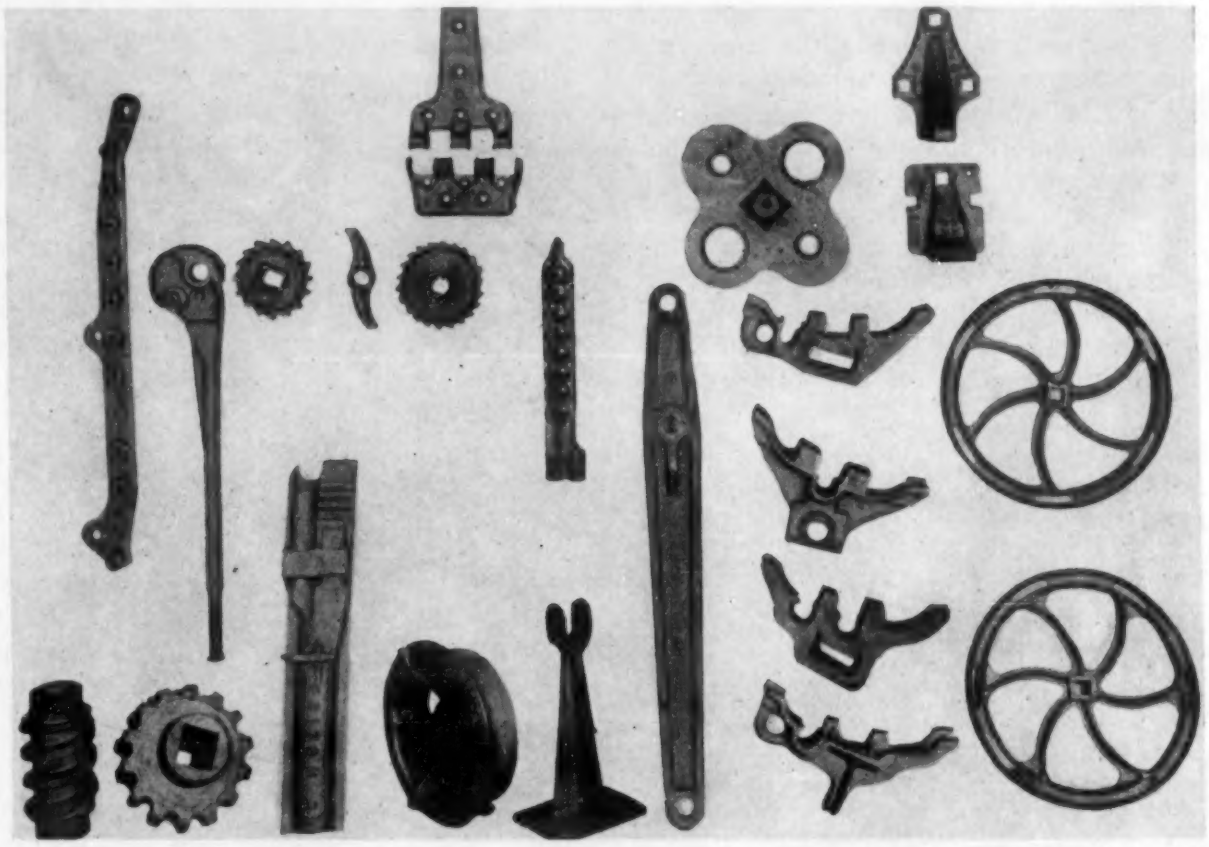


Fig. 8. **Miscellaneous railway castings. Courtesy Malleable Iron Research Institute.**

It was found that up to the point where one-half the cementite had been destroyed at a given temperature above A_1 the amount of carbon was proportional always to the $1^1/_2$ power of time. It was further found that equal increments of temperature multiplied graphitizing rates by equal amounts regardless of temperature. The rate of multiplication is near 1.23 for an increment of 10° C. in temperature and varies somewhat with silicon content. The relation between silicon content and graphitizing rate was also logarithmic.

A detailed quantitative discussion of the phenomena was summarized by the writer[24] elsewhere.

A considerable amount of study has been given to annealing cycles, some of which has found expression in patents.

Valentine,[25] reports an acceleration of annealing below A_1 by an abrupt change of temperature of about 10° or 20° C. in this region irrespective of the direction of this change provided only it be near but below the critical point.

Hayes and Diederichs[26] claim an acceleration by oscillations of temperature passing through the A_1 temperature.

Piwowarski[32] refers to a quick annealing iron containing nickel and sometimes chromium and having a sorbitic or pearlitic matrix. The data given indicate a low total carbon, 1.82 to 2.09%, a high silicon, 1.56 to 1.63%, a high manganese, 0.74 to 0.84%, low phosphorus, around 0.02% and a similar sulphur.

The annealing time and properties of such metal with and without nickel and chromium additions, were reported as follows:

Ni	Cr	Hours at 975° C.	Ultimate Strength lbs./in.^{2}	Elongation in 5 Diameters %
Nil	Nil	1.0	88,000	2.0
			92,200	4.0
1.00	Nil	1.5	82,300	2.0
			88,000	3.0
2.48	Nil	2.0	73,700	1.5
			92,200	2.0
2.55	0.46	3.0	99,300	0.5
			127,800	1.0

It is somewhat doubtful whether such metal should be called malleable cast iron in American usage. A number of producers in the United States have interested themselves in intermediate products made by suppressing wholly or in part, the graphitization of pearlite below A_1. The properties

[20] R. Schenck. Gleichgewichtsuntersuchungen über die Reduktions, Oxydations-und Kohlungsvorgänge beim Eisen, V. *Zeitschrift für anorganische und allgemeine Chemie*, Vol. 167, 1927, pages 315–328.
[21] O. W. Storey. A Study of the Annealing Process for Malleable Castings. *Metallurgical and Chemical Engineering*, Vol. 12, June 1914, pages 383–389.
[22] H. A. Schwartz. Graphitization at Constant Temperature. *Transactions of the American Society for Steel Treating*, Vol. 9, 1926, pages 883–906.
[23] H. A. Schwartz and H. H. Johnson. Graphitization at Constant Temperature below the Critical Point. *Transactions of the American Society for Steel Treating*, Vol. 10, 1926, pages 965–968.
[24] H. A. Schwartz. The Mathematics of Graphitization below the Solidus. World Engineering Congress, Tokyo, Japan, 1929.
[25] I. R. Valentine. Malleable Iron-Short Cycle Anneal. *The Foundry*, Vol. 57, Oct. 1, 1929, pages 825–826; *Metals & Alloys*, Vol. 1, Nov. 1929, pages 233–234.
[26] U. S. Pat. Nos. 1,574,374; 1,574,376 and 1,574,377.
[27] A. Phillips and E. S. Davenport. Malleableising of White Cast Iron. *Transactions of the American Institute of Mining and Metallurgical Engineers*, Vol. 67, 1922, page 466–488; discussion, pages 489–497.
[28] U. S. Pat. No. 1,634,586.
[29] Saito and Sawamura. A New Phenomenon Concerning the Graphitization of White Cast Iron and its Application to the Manufacture of Black Heart Malleable Castings. *Memoirs of the College of Engineering*, Kyoto Imperial University, Vol. 5, No. 1, 1927.
[30] U. S. Pat. No. 1,688,438, Oct. 23, 1928.
[31] U. S. Pat. No. 1,591,598.
[32] E. Piwowarski. La Malléable à haute resistance. *Congrès International de Fonderie*, Liege, June 1930.

of heat treated malleable were discussed by E. K. Smith.[33] The properties in general are those which might be expected if for the ferrite matrix of malleable, a pearlitic or other steely structure be substituted, i. e., an increased strength and decreased elongation.

Lauenstein[34] has announced a metal in which the recarburization on heat treatment is confined to the grain boundaries for which he claims superior properties as regards high strength with reasonable ductility.

Marshall[35] investigated the embrittlement of malleable on heating into the blue heat range as in galvanizing and found it could be prevented by quenching the malleable after anneal and before processing from temperatures of the order of magnitude of 650° C.

Bean[36] had previously found that the embrittling phenomenon was present only if the total amount of silicon and phosphorus exceeded certain limits.

The preceding review has been prepared keeping in mind the following limitations. The inclusion of such matter only as has been given to the public either in technical publications or patents; omission of scientific investigations, as for example, on equilibrium diagrams, not directly related to the malleable founder's art.

Agricultural Implements
Automobiles
Boilers, Tanks and Engines
Building Equipment
Conveyor and Elevator Equipment
Electrical and Industrial Power Equipment
Hardware and Small Tools
Household Appliances
Machine Tools
Machinery for Special Uses
Marine Equipment
Metal Furniture and Fixtures
Municipal, State and Public Service
Pipe Fittings and Plumbing Supplies
Railroads
Road and Contractor's Machinery
Toys and Specialties.

The original articles should be consulted for the particular applications in each industry.

Emphasis is laid upon the fact that the statements frequently encountered that malleable iron is similar to a superior character of gray iron and that the malleable process is not effective very far below the surface are entirely fallacious and arise out of ignorance of the processes employed and the results obtained.

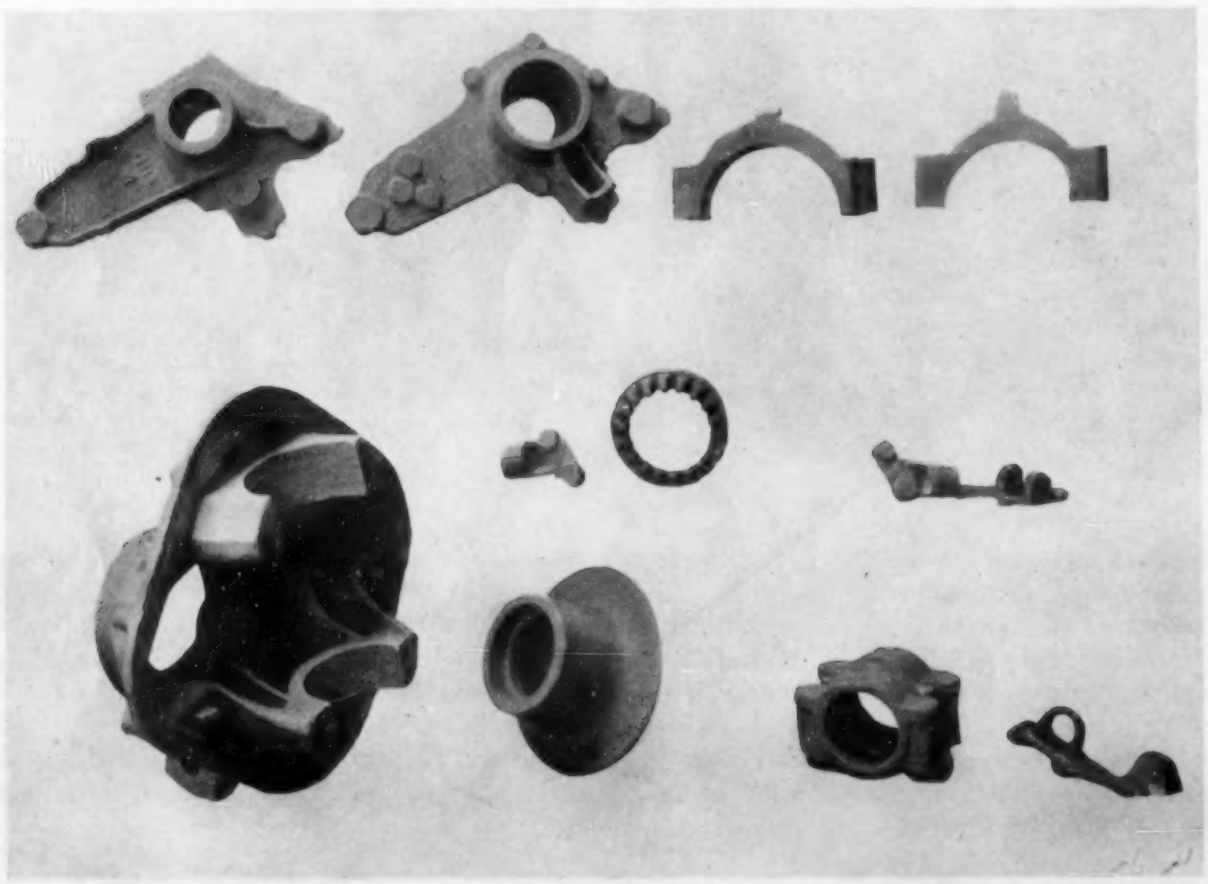


Fig. 9. A number of automotive castings. Courtesy Malleable Iron Research Institute.

No exhaustive searches for priority are implied in the assignment of credit. There may have been anticipation of publication in obscure periodicals or by workers who did not choose to publish. Developments in equipment in the industry are not covered.

The Symposium on Malleable Iron under the joint auspices of the A. F. A. and A. S. T. M. at the 1931 meeting of the latter association contains a very extensive résumé of the methods of manufacture and of the physical properties of the product as now marketed. Reference is there also made to the use of malleable castings in the following industries:

The following physical constants are accepted: Specific gravity 7.15 to 7.45, coefficient of thermal expansion as usual, varies with the temperature; the expansion increasing more rapidly than the temperature. The precise relation is shown graphically but is equivalent to a change of 0.000012 of the original length for 1° C. at temperatures not too far removed from ordinary room temperature values. Specific heat similarly varies with temperature and is approximately 0.122 calorie/g./° C. near room temperature. A survey of some 20,000 heats is made and it is concluded that the tensile strength averages about 54,000 lbs./in.^{2}, the yield point in tension 36,000 lbs./in.^{2} and the elongation 18%. The modulus of elasticity in either tension or compression is in the neighborhood of 25,000,000 lbs./in.^{2}; the ultimate strength in shear as given is 48,000 lbs./in.^{2}, the yield point in shear

[33] E. K. Smith. Hardened and Tempered Malleable Castings. *Transactions of the American Foundrymen's Association*, Vol. 31, 1923, pages 295–312.
[34] U. S. Pat. No. 1,760,241.
[35] L. H. Marshall. Embrittlement of Malleable Cast Iron Resulting from Heat Treatment. *Technologic Paper* No. 245, U. S. Bureau of Standards, 1923.
[36] W. R. Bean. Deterioration of Malleable in the Hot-Dip Galvanising Process. *Transactions American Institute of Mining and Metallurgical Engineers*, Vol. 69, 1923, pages 895–931.

is about 23,000 lbs./in.², the modulus of rupture in torsion 58,000 lbs./in.², the yield point in torsion 24,000 lbs./in.² The data for modulus of elasticity and those following are based on relatively few samples.

The Brinell hardness number is shown to be somewhat variable and this number is not believed to be particularly useful as determining the quality of product; it is usually about 115 and may run from 100 to 140. Notched bar impact tests on the usual Charpy apparatus will run about 7¾ ft.-lbs. and the Izod value will be about 9 ft.-lbs.

The resistivity of the material is from 28 to 37 microhms per centimeter cube depending largely upon carbon content. The magnetic properties are given in curve form and it may be worth mentioning that below flux densities of approximately 9000 kilo-gausses/cm.², the permeability is higher than that of any material made and sold under comparable conditions.

Efforts have been made to analyze statistically the available data for tensile properties to determine an expression of uniformity. The fundamental data are collected from about 5000 specimens tested in the laboratory of the Malleable Iron Research Institute.

The standard deviation of tensile strength is computed as about 1980 lbs./in.², of yield point about 1000 lbs./in.² and of elongation about 4%. The standard deviation of any quantity is a measure of the scatter of results obtained in its observations. It is calculated by taking the square root of the sums of the squares of all the differences between the observed values and the mean value, divided by the number of observations; i. e., it is the root mean square of the individual deviations from the average.

A section of the Symposium is occupied with a discussion of the fact that, unlike any other commercial ferrous material, in malleable iron, the tensile strength and elongation vary in the same direction, the stronger iron having the greater elongation. Reference is made to the connection between this fact and the attainment of good impact values.

It is also pointed out that although the surface layers being low in carbon may be higher in tensile strength and elongation than the center of the bar, these differences are by no means so pronounced as to warrant the conclusion that malleable iron with its surface removed is materially worse in physical properties than with the skin on. The physical properties to be expected from machined bars are elucidated in the text.

Certain special malleable iron of high strength and low carbon content is described; this material had an average tensile strength of 57,700 lbs./in.², a yield point of 38,000 lbs./in.² and elongation of 25%. The standard deviations of these quantities are about 1140, 635 and 1.3, respectively. The high strength metal was evidently of more uniform quality besides of higher physical properties; this greater uniformity is in part at least due to the fact that unlike the metal first quoted, it was made in one plant to a single specification and should therefore, of course, be more uniform than the product of many plants made for a variety of purposes.

Machinability could not be covered quantitatively but the statement is made that irrespective of grade, properly made malleable is the most machinable ferrous material.

A brief discussion is given of the properties of cupola malleable iron as made for pipe fittings and similar service.

The data available to the Committee in regard to cupola iron were much less voluminous than in regard to air furnace and electric metal.

The average ultimate strength and average elongation reported are lower in cupola metal than these constants were found to be for air furnace and electric metal. Two producers found the yield point to be very close to that prescribed in the current specifications; another found it to be much higher.

No mathematical discussion of the degree of uniformity of results was undertaken.

The Symposium closes with a series of recommendations to engineers which may be summarized in the following quotation:

"1. The stock of the casting should be as nearly uniform as possible, avoiding direct connection of heavy sections to light sections. Shrinkage cracks will develop at points of quick change of section. Where it is necessary to vary metal from light to heavy sections, a gradual taper of the joint should be developed.

"2. When heavy sections or bosses are surrounded by light sections, it is impossible to secure proper feeding of the boss, resulting in unsoundness. This trouble can be overcome by placing ribs of sufficient section on the light parts to permit feeding.

"3. Cross-sections such as ribs forming a cross should at all times be avoided.

"4. The design should be made sufficiently heavy or thick to permit adding a gate of such size as to insure good feeding of all sections.

"5. Use as large fillets as possible and avoid sharp corners.

"6. Avoid dry sand cores wherever possible, especially where castings on cooling contract around a core.

"7. Parting lines should be made as even as possible.

"8. Designs should be such as to provide ample draft for easy molding."

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RESEARCH LABORATORIES INSPECTION TOUR

Executives of various branches of the metal industries, will be members of a party of 100 business men and bankers on a tour of research laboratories this fall that is being organized under the sponsorship of the National Research Council to acquaint the group with the scientific research activities now carried on by all classes of industry, small and large, in a period of changing economic conditions, looking to such factors in business re-adjustment as creation of new products and the development of new markets.

Professor Dugald C. Jackson, head of the electrical engineering department of Massachusetts Institute of Technology, who is chairman of the Division of Engineering and Industrial Research of the National Research Council conducting the tour with headquarters in the Engineering Societies Building, 29 West 39th Street, New York, has announced the itinerary of the tour as follows:

Monday, October 5, the party will leave for Boston on one of the boats of the Eastern Steamship Lines. The remainder of the trip will be made by special train. Tuesday, October 6, Massachusetts Institute of Technology, the laboratories of Arthur D. Little, Inc., Dewey and Almy Chemical Company, and the New England Confectionery Company, all in Cambridge, Mass.; the United Drug Company and the Thompson and Lichtner Company, Inc., in Boston. The tour activities in and around Boston will be in charge of the New England Council, an organization which promotes interest in New England industries. Members of the party will be given a choice of visits to the laboratories just named. Wednesday, October 7, Eastman Kodak Company, Rochester, N. Y.; Thursday, October 8, Ford Motor Company, Detroit; Friday, October 9, Nela Park Laboratories, Cleveland; Saturday, October 10, Goodyear Tire and Rubber Company and Zeppelin Plant Laboratories, Akron; Monday, October 12, Tanners' Council of America; and the Basic Science Research Laboratory, identified with the General Foods Corporation, both at the University of Cincinnati; Tuesday, October 13, Battelle Memorial Institute, Columbus; Wednesday, October 14, Westinghouse Electric and Manufacturing Co., East Pittsburgh and Thursday, October 15, return to New York City.

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Lukenweld, Inc. (division of Lukens Steel Company, Coatesville, Pa.) has appointed W. R. McDonough & Co. as representative in Cleveland District and the Dravo Doyle Company in the Pittsburgh territory. Lukenweld, Inc., is engaged in the design and manufacture of parts of machinery and equipment by gas-cutting, forming and arc welding of rolled steel, its products being known as Lukenweld Construction.

Present Position of NITRALLOY in INDUSTRY

BY M. A. GROSSMANN[2]

This article will deal with the questions:
How is Nitralloy made and treated, and why?
What are its advantages in use?
Where has it proven disappointing?
How expensive is the metal and what is the cost of the treatment?

IT OFTEN happens that when one man tells us something, it doesn't entirely register. If two people tell us about the same thing in different words, we are more likely to get the story.

We are therefore trying the experiment in this issue of having two authorities on the subject of nitriding, discuss it, each from his own point of view.

Grossmann deals with a particular composition of nitriding steel, varying only in carbon content, while Harder covers a wider range of compositions. Their conclusions agree in all essentials.

THE INVENTORS of any new material usually feel that they are entitled to a certain time for industrial experimentation so that they may "work out the bugs in it." Let us discuss the entomology of Nitralloy, and examine some of these bugs and the extent to which they have been exterminated, if any.

Since the original investigations by Fry, a really tremendous amount of work has been done in the attempt to standardize the practice in manufacture and in treatment. As is the case with any kind of steel having wide consumption, the steel must have a composition which can be made regularly and uniformly in the melting furnace, and can be treated to give uniform and reproducible results.

Table 1 shows a composition which has proven very successful and is being used widely. It will be noted that there are four different carbon contents, which are used because they give four different core strengths and degrees of ductility. The alloying elements are however the same in all four grades.

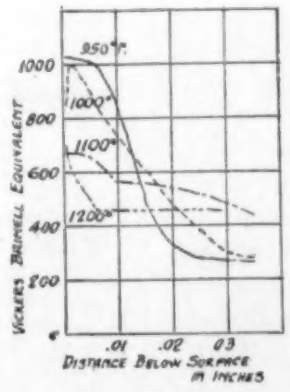


Fig. 1. Heat 3305, C–0.315, Mn–0.63, Si–0.15, Cr–1.68, Mo–0.19, Al–0.70.

Temp.	Time	Dissoc'n	Flow
950° F.	48 hrs.	25%	200
1000° F.	48 hrs.	40%	200
1100° F.	48 hrs.	75%	500
1200° F.	48 hrs.	90%	500

Table 1.

Type	C	Mn	Cr	Mo	Al
I	0.10/0.20	0.40/0.70	0.80/1.30	0.15/0.25	0.60/1.20
H	0.20/0.30	"	"	"	"
G	0.30/0.40	"	"	"	"
High C	0.55/0.65	"	"	"	"

The aluminum content was adopted after many trial heats had been made, both on a laboratory scale and commercially in the plant. The value shown is the amount which will give adequate hardening, with an extra percentage of aluminum for safety. If the aluminum content is too far below the figures shown, the Nitralloy will not develop enough hardness on treating.

The upper limit is influenced by the ease of melting—if too much aluminum is used, it is difficult to get it distributed perfectly evenly throughout the heat. The low specific gravity of the metallic aluminum or ferro-aluminum is responsible for this difficulty. Furthermore, too high an aluminum content would introduce another difficulty—the hardened case after nitriding would be too hard and brittle, and would be very shallow relatively if the steel contained too much aluminum.

The amount of chromium shown has been found to be the proper amount to combine good depth of case with proper ductility and strength.

The molybdenum supplements and assists the nitrogen-hardening properties of the aluminum.

The variation in carbon content has already been referred to—where core strength is desired, in order to resist pressure in service, higher carbon contents are used. Where ductility in forming or machining is needed, the lower carbons are desirable.

The next consideration is the condition of the steel when subjected to the nitriding process. It was found early that steel which had been decarburized gave a brittle surface when nitrided. Further, it was found that if appreciable areas of free ferrite were present in the structure, they behaved just as badly in nitriding as does a decarburized surface. Nitralloy in the annealed condition has a structure embodying a considerable proportion of ferrite. These ferrite areas develop nitride needles and give a brittle case.

To avoid this condition, the Nitralloy before nitriding is heated to about 1700° F. and is quenched or air cooled, being then reheated usually to 1300° F. This results in a so-called normalized structure, free of appreciable ferrite areas. A majority of the unexpected failures are attributable to a decarburized surface.

The nitriding is done with ammonia gas, and there is little likelihood at present of finding any other material which meets the requirements so efficiently and so cheaply.

The temperature for nitriding has been the subject of much investigation. The temperature in common use is 950° F. (510° C.) and has been adopted for the following reasons. If a lower temperature is used, the time is increased inordinately, without any corresponding advantage in mechanical properties. If a higher temperature is used, the resulting hardness of the case is less. This latter point is illustrated in Fig. 1, which shows the hardness of case developed at various nitriding temperatures up to 1200° F. The curves show not only surface hardness (at the left of the diagram) but also gradation of hardness toward the interior of the piece (at the right of the diagram). The curves are plotted in the following way: the finished nitrided piece is ground on a plane at an angle of 3° with the original nitrided surface, so that this freshly ground surface traverses the case and enters the core. The hardness at the extreme surface is plotted at the left (the origin) in the diagram, and the hardnesses at various depths along the 3° taper are plotted as shown.

The several curves on the chart show that as the temperature of nitriding is raised, the surface hardness obtained be-

[1] Condensed from a talk before the Washington-Baltimore Chapter, American Society for Steel Treating.
[2] Vice-President and Director, Republic Research Corporation.

Fig. 2

comes materially less. For most purposes, a piece nitrided at 1000° F. might be useful, but one nitrided at 1200° F. would not be.

However, associated with the lesser surface hardness, a somewhat greater depth of case is obtained at 1200° F., as is observed in Fig. 1, and this circumstance can be made use of. If all of the nitriding were to be carried out at 1200° F., the hardness at the surface would be too low, but advantage may be taken of the greater depth of case at 1200° F. by using a duplex cycle. The first portion of the cycle is carried out at 950° F. and gives the surface hardness shown in the diagram. Investigation has shown that when a piece has once been nitrided at 950° F., it may be heated to a higher temperature without losing its hardness. In other words, a piece hardened at 950° F. may then be heated to 1200° F. and the surface hardness will remain at approximately the value obtained at 950° F. If, then, we nitride a piece for a short time at 950° F. we obtain high surface hardness, and if we nitride the same piece subsequently at 1200° F., greater depth of case is imparted, in less time than would have been possible if the nitriding had been continued at 950° F. The duplex cycle consists therefore in nitriding first at 950° F. to obtain surface hardness, and to continue the nitriding then at 1200° F., to increase the depth of case and so improve its strength and resistance to crushing.

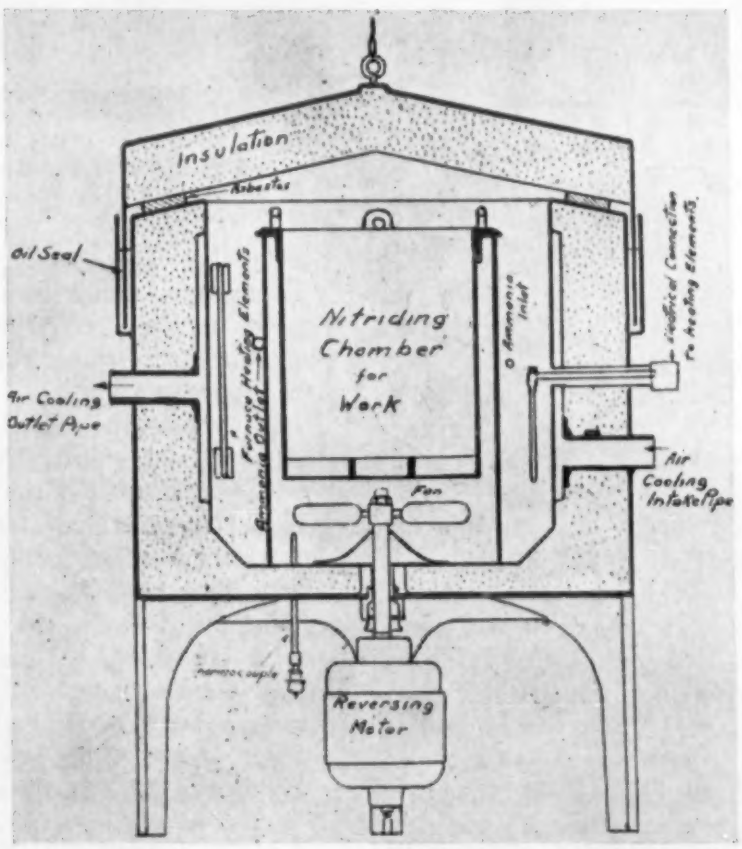


Fig. 3

The above, then, are the procedures which have come to be considered as tentative standards for the preparation of the nitriding steel itself, and for the imparting of a satisfactory nitrided case. There are, however, many accessory steps which have involved considerable experimentation.

One of these is the protection of certain areas of a piece from nitriding, so that these areas will remain soft while the rest of the article will be hardened. The most satisfactory and most reliable method is to apply a coating of tin to the areas to be protected, either by hot tinning or by electroplating. The tinned areas are impervious to the action of the ammonia. Other methods include nickel plating, also the application of mixtures of salts and water-glass, but these have on the whole been found to be less reliable than tinning.

Fig. 2 shows on the left the protective action of a coating, and on the right the junction between a protected area and an unprotected area. In the photograph on the right, one portion became nitrided, and this region darkened when etched.

Of importance further is the kind of furnace used for nitriding. It has been found extremely useful to have thorough circulation of the nitriding gases in the furnace. For this reason the type of furnace shown in Fig. 3 has proven to be of value. Here a circulating-fan causes the gases to circulate constantly, leading to very much greater uniformity of nitriding on various pieces and even on different parts of the same piece, than has been found possible without circulation of the gases.

A further important practical consideration is the container in which the nitriding is carried out. Due to a deterioration of the container when it is used over a period of a number of months, the efficiency of the gases as nitriding agents is gradually reduced. Two types of container have proven particularly free of this defect. One is a European development—an alloy steel with 25% chrome and 20% nickel. The other, a domestic development, is a container enameled on the inside.

With the above details of practice, we come now to applications of the process.

Nitralloy introduced hardnesses of a new order of magnitude for steel treating. Indeed, it is significant of these hardnesses that new hardness testers were developed for use especially with these steels. It is now common practice to report Nitralloy hardness in terms of Vickers Brinell or Firth Brinell—the so-called Brinell-equivalent measured on Vickers or Firth diamond indentation machines.

It is common knowledge that the hardnesses obtainable in previous materials were of the order of 700 Brinell, whereas with nitriding the hardness is commonly around 1000 Brinell equivalent. With such high hardnesses, the applications to practice were bound to be abundant. Of the numberless applications, we list a dozen of the most important to date, as follows:

Valves (steam)
Crankshafts for heavy duty motors
Pump shafts (auto)

Fig. 4

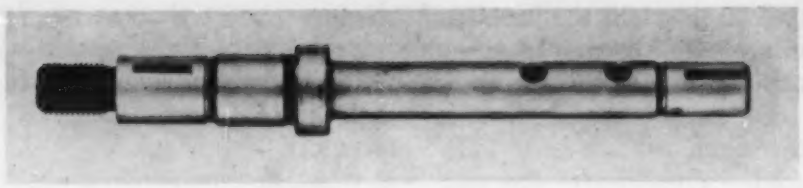


Fig. 5.—Pump Shaft.

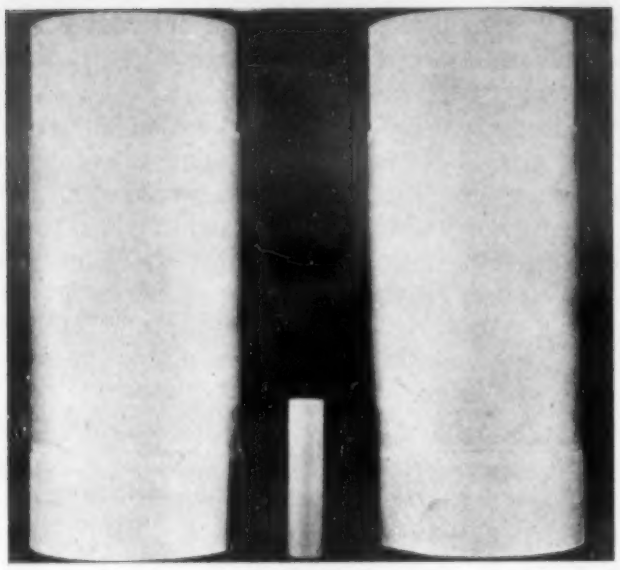


Fig. 7.—Gas Engine Wrist Pins and Automotive Wrist Pin.

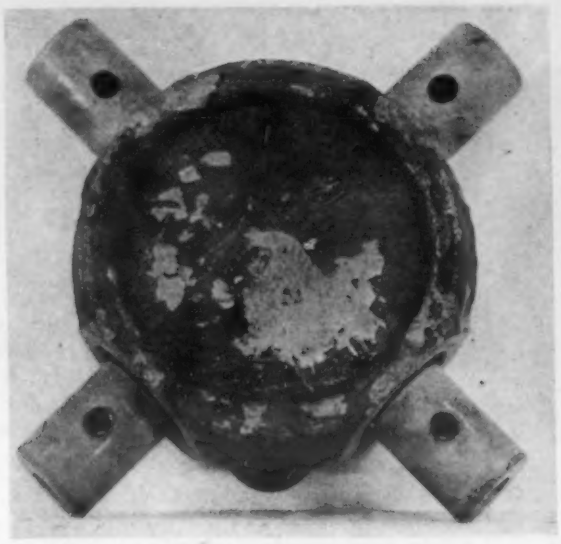


Fig. 6.—Universal Cross.

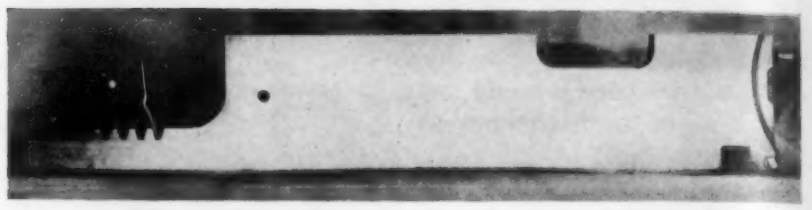


Fig. 8.—Bar for Crankshaft Turning Machine.

Cross for universal joints
Camshafts
Piston pins
Cross head guides in R. R. engines
Large machine parts too large to harden by quenching
Small gears under light load
Small machine parts generally
Forging dies for shallow forgings
Steam joints in connecting R. R. cars

Figs. 4–7 shows a few typical applications. Fig. 8 shows a large piece in which, on account of the thickness of section, it would have been particularly difficult to secure surface hardness by quenching, but it was easily secured by nitriding.

Since Nitralloy is, however, hard to a modest depth only, we find it necessary to remember this feature. It is convenient to report the hardness in the form of a curve, showing the gradation of hardness from surface to core, as explained previously. Fig. 9 shows typical curves comparing nitrided cases with carburized and quenched cases. The curve shows the now familiar high hardnesses around 1000 Brinell-equivalents. But it also indicates the other and less happy feature—the relatively shallow depth of case. And it must be remembered incidentally that the Vickers and Firth testers are important not only because they measure high hardnesses, but also because they are adapted to measuring a thin case—the applied load (10 kg.) is so light that a thin case can be tested without breaking through.

Because nitriding is a case-hardening process, the supposition is often voiced that Nitralloy is now by way of replacing all carburizing steels. But this cannot be accepted without reservation.

Fig. 9 shows the relative surface hardness and the relative depth of case of nitrided and case-carburized steels. The hardness and with it the wear resistance is of course all in favor of the nitrided steel. The depth of case is, however, much greater in the carburized steels. This means that their resistance to impact and crushing is greater than that of nitrided steels. On the other hand, accidental heating in service reduces the hardness sooner (that is, at lower temperatures) in carburizing steels, so that such reheating in service is much more likely to be harmful in carburized steels than in nitrided steels. This loss of hardness by reheating is illustrated in Fig. 10. In the nitrided steels there would of course be no loss of hardness until the temperature of nitriding itself had been passed.

There is evidence that Nitralloy, with its higher hardness, shows better wear resistance than ordinary steels or irons. As a matter of fact, instances could be adduced endlessly where nitrided pieces have given many times the life of ordinary steel. Table 2, from Guillet, shows a striking difference. There is every reason to believe that for wear resistance Nitralloy is in reality unexcelled in its field.

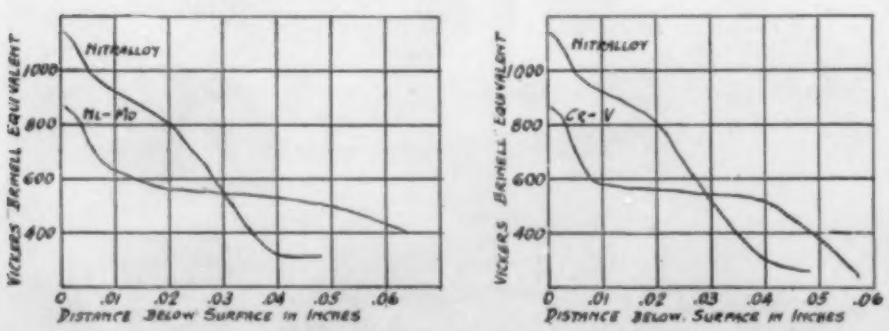


Fig. 9. Nitrided vs. Carburized Case Hardness. Nitralloy–Heat Treated and Nitrided 90 hrs.–975° F. Ni-Mo–Carburized–Double Oil Quenched and Drawn at 300° F. Cr-V–Carburized–Double Water Quenched and Drawn at 300° F.

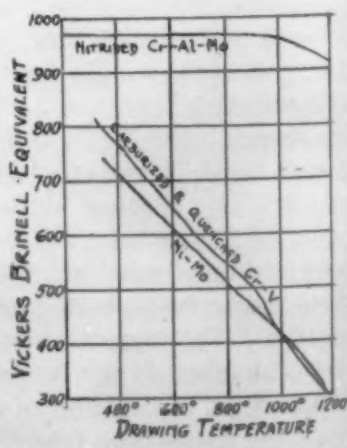
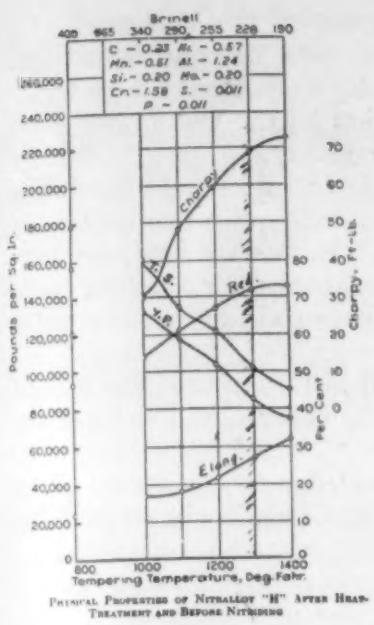
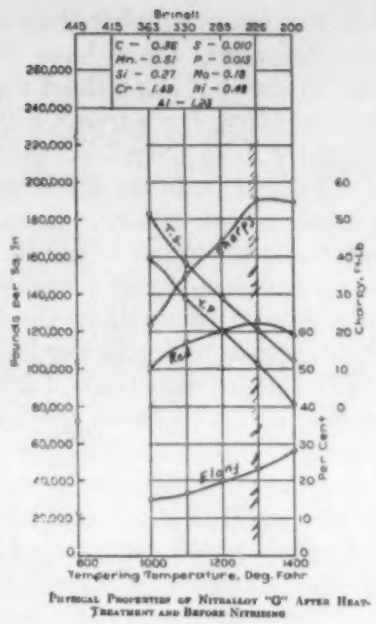


Fig. 10. Effect of Reheating on Nitrided Steel and on Carburized and Quenched Steels.



Physical Properties of Nitralloy "H" After Heat-Treatment and Before Nitriding

Fig. 11



Physical Properties of Nitralloy "O" After Heat-Treatment and Before Nitriding

Fig. 12

Table 2.

	Wear of Motor Cylinders	
	Cast Iron	Nitralloy
Automobile, 18,000 miles	0.0160	0.0008
	Steel	Nitralloy
Aviation motor, 100 hours	0.0032	Not measurable, probably under 0.0005

Wear of Motor Cylinders Indicated by Oil Consumption in Use

	New Motor	After 100 Hours
Heat-treated steel	5	15 g. p. hp.-hr.
Nitralloy	5	5

On the other hand, the strength of the core is occasionally insufficient. This strength of core can be regulated to a certain extent, especially by using a higher carbon content, but the fact that nitriding is carried out at 900° to 950° F. means that only moderate strength can be retained from any previous heat-treating operation. Figs. 11 and 12 show the core strengths, and they are not as high as might be desired. Associated with this reduced core strength is the previously mentioned shallowness of case, with the result that Nitralloy will not withstand the highest impacts. In impact and clash gears, for example, the present commonly used grades of Nitralloy are as yet unsatisfactory.

There is another feature about which a good deal has been said: namely, that due to the fact that Nitralloy is hardened without quenching, there is almost complete absence of distortion. Confidentially, we have to admit that in these days of quenching in jigs and fixtures, the advantage is not as striking as one could hope, but the fact does remain that large pieces, and pieces of complicated cross section, can be hardened easily with but little distortion. The freedom from

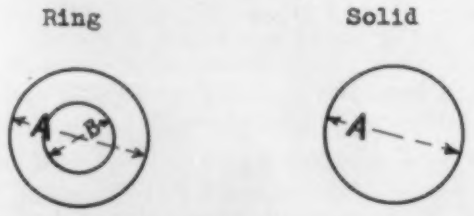


Fig. 13

A	B		A
0.918	0.500	Before	0.918
0.9215	0.502	After	0.920

distortion is indeed not absolute, for there is a slight growth in nitriding, and with very uneven pieces there may therefore be a slight distortion, which is accentuated if for any reason a high nitriding temperature is employed.

This growth in nitriding is illustrated in Fig. 13, which shows that in a 1-inch ring and a 1-inch disc, there is an increase in size amounting to 0.001 to 0.003 inch. If a couple of

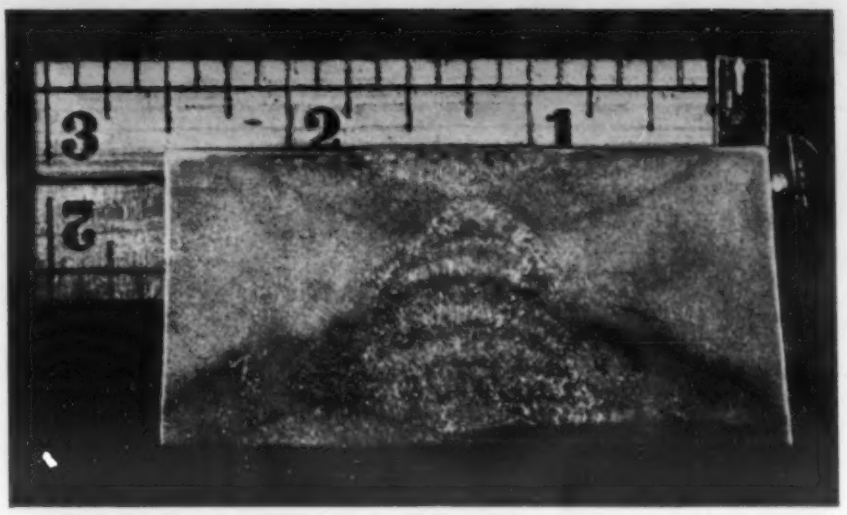


Fig. 14

thousandths is of importance, therefore, it must be allowed for.

One further point: if the article is a thin piece, and is protected on one side from nitriding (as by tinning), the nitrided side will grow slightly while the protected side retains its original dimensions, resulting in curvature of the finished piece.

But these are unusual circumstances, and in general the freedom from distortion is very satisfactory.

There are a few further advantages and disadvantages which have come to light. Among the advantageous items is the rust resistance. Nitrided articles exhibit a very fair degree of resistance to corrosion. It should be noted how-

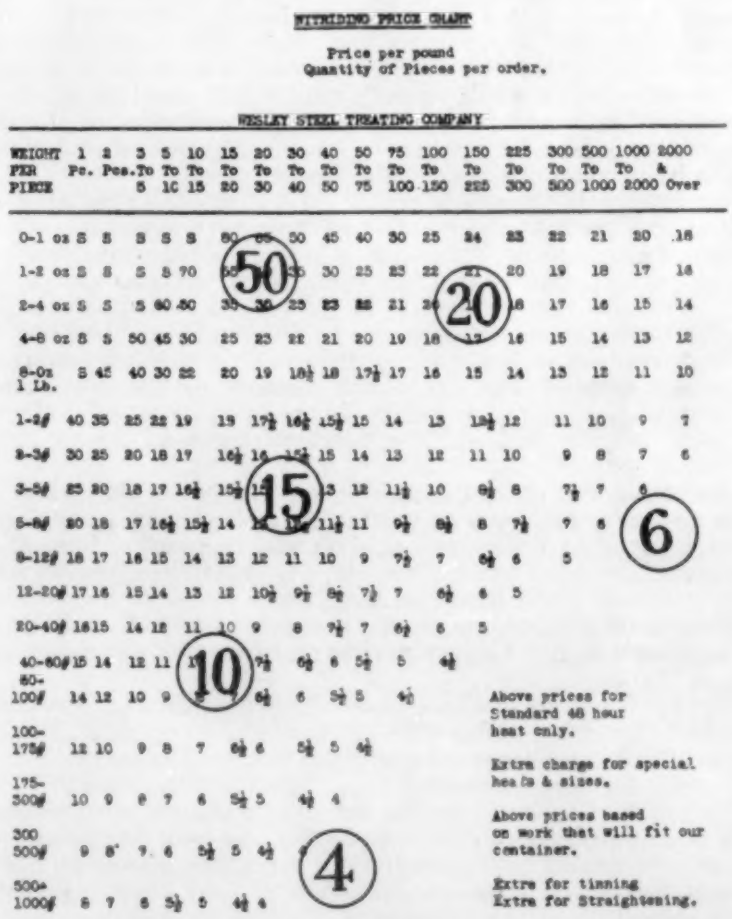


Fig. 15

ever that the original nitrided surface should be preserved, for the removal of as little as 0.002 inch (as by grinding) materially lowers the rust resistance. There is reason to believe that a nitride compound forms at the surface, that it is this compound that is rust-resistant, and that if the compound is removed as by grinding, the underlying material is no longer rust resistant. Also, rust resistance does not mean

resistance to acid, for mineral acids attack Nitralloy. In acids the resistance is poor, in corrosive oils and in salt water the resistance is excellent.

Another advantageous item is the fact that it has been found possible to weld Nitralloy using the atomic hydrogen weld with Nitralloy welding wire. Fig. 14 shows a weld which was subsequently nitrided to a hardness above 800 Vickers Brinell.

Now as to the cost. It is an open secret that this was a serious impediment for some time. We say "was an impediment," because the recent more widespread use has brought with it notable reductions in cost. The two factors are, of course, the cost of the steel itself and the cost of the nitriding. As to the steel itself, the regularly quoted prices now carry reductions up to 25% on large lots. But of the economies effected, the greatest have come in the cost of the nitriding itself. For a considerable time, the cost of this nitriding operation was always higher than the cost of the steel used. Of late, however, there have been very marked reductions. Fig. 15 shows a price chart used by a commercial heat treating company, for various nitriding jobs. The large figures in circles have been inserted for clarity, to show the range of prices. Obviously for large pieces, or for large quantities of small pieces, the cost is less and the price quoted here is seen to be as low as 4c per lb. Even this has now been bettered, and in a recent furnace installation for handling large quantities in production, the furnace company guaranteed a nitriding cost under 2c per lb.

The general drawback of cost, which for a time was indeed serious, seems to be on the way to being solved through increased production.

It is a great pleasure to acknowledge the assistance given by Messrs. R. Sergeson and M. M. Clark, in the preparation of the data presented here.

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NEW USES FOR THALIUM

THE PHYSICAL and chemical properties of thallium are very similar to those of lead, states Alice V. Petar, in a report recently published by the Bureau of Mines. The metal is white with a bluish-gray tinge, somewhat paler than lead. It has a bright metallic luster when freshly cut but dulls quickly when exposed to air. Thallium is softer than lead; it can be scratched by the finger nail and is easily cut with a knife. It is malleable but has little tenacity, and can be squeezed but not drawn, into wire.

There are no commercial ores of thallium, although it is present in small quantities in a great many minerals. The supply was formerly obtained solely from flue dusts that accumulated in sulphuric acid plants where pyrite is used. The thallium content of these flue dusts is small—usually about 1/2%—and the thallium is produced only as a by-product. At present most of the domestic supply is a by-product of the purification of cadmium, itself a by-product of the smelting of other metals.

Four very rare minerals contain appreciable percentages of thallium. Crookesite, a thallium-copper-silver-selenide, which contains from 16 to 19% thallium, is found in Skrikerum, Sweden. Lorandite, a sulphide of thallium and arsenic, contains from 59 to 60% thallium and is found in Macedonia. Hutchinsonite, a sulphoarsenide of thallium, lead, silver and copper, has a thallium content of from 18 to 25%. This mineral occurs in white dolomite of the Legenbach Quarry in the Binnental, Switzerland. Vrbaite, found in Macedonia, is a sulphide of thallium, arsenic and antimony which contains 29 to 32% thallium.

Thallium is also present in small quantities in a great variety of rocks and minerals, such as pyrites, zinc blende, hematite, lepidolite, muscovite, orthoclase, pitchblende, berzelinite, frenzelite, pyrolusite, manganite, carnallite, etc. Owing to its occurrence in some of the common minerals, thallium is found in commercial products such as zinc, cadmium, platinum, bismuth, tellurium and sulphuric acid. Copper pyrites and iron pyrites frequently contain thallium.

Alloys of lead and thallium are somewhat unusual in that they have higher melting points than either of the component metals; they are used in rather small quantities in special types of electrical fuses. An alloy containing 10% thallium, 20% tin and 70% lead is resistant to the corrosive action of mixtures of sulphuric, nitric and hydrochloric acids. This alloy has been recommended for use as an anode for the electrolytic deposition of copper, since its corrosion is less than one-fifth that of lead alone. Experiments indicate that the addition of thallium to lead-base alloys markedly improves their resistance to deformation.

Many uses have been found for thallium compounds. By far the most important commercial outlet for the element is the utilization of thallium sulphate as a poison for rodents and as an insecticide for ants. The sulphate has the advantage of being tasteless and odorless.

Because of their high refracting power, thallium compounds are used in the manufacture of certain kinds of optical glass in which a high refractive index is required.

The oxysulphide of thallium is used in the "Thalofide" cell, which is more sensitive to light, especially that of low intensity and long wave length, than the selenium cell. Its electric resistance drops 50% on exposure to a quarter-foot candle.

The use of thallium and its compounds to prevent knocking in internal combustion engines has been patented. According to the patent specifications, thallium or thallium oxide may be vaporized outside the cylinder by an electric arc or a thallium compound may be mixed with the fuel or otherwise injected into the engine. The compounds which may be used include thallium ethyl, benzylate, phenylethylate, oleate, amylalcoholate and acetoacetate.

A liquid amalgam containing 8.5% of thallium has been used in thermometers for recording temperatures as low as −60°.

Thallous chloride has found use as a "getter" in tungsten lamps to prolong the life of the filament. It is one of the few lower chlorides that is more stable than the compound of the higher state of oxidation.

In a study of heavy liquids for mineralogical analyses the Bureau of Mines found that the most suitable liquid for sink-and-float work on minerals of high specific gravity was a water solution of the double thallous formate-malonate.

Thallium acetate has been used for the treatment of certain kinds of tuberculosis and ringworm. At one time it was used as a depilatory.

The demand for thallium and its salts is not large. The only compound of thallium that has attained any marked commercial development is the sulphate, and it is understood that this demand is being taken care of largely by importations from Germany. No figures covering imports are available.

Early in 1931 thallium metal was quoted at from $12.50 to $15 per pound, and the sulphate was selling at prices ranging from $10 to $15 per pound.

The discovery of thallium dates back to the early part of 1861, when W. Crookes noted a bright green line in the spectrum of the selenium residues from a sulphuric acid factory in the Harz Mountains; he was looking for tellurium, but spectroscopic examination revealed the presence of an unknown element, to which he gave the name "thallium,"—"from the Latin thallus, a budding twig—a word frequently employed to express the beautiful green tint of young vegetation in spring."

Further details are given in Information Circular 6453, which may be obtained from the United States Bureau of Mines, Department of Commerce, Washington, D. C.

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Dr. Robert F. Mehl, formerly Superintendent of the Division of Physical Metallurgy, at the Naval Research Laboratory, joins the research staff of the American Rolling Mill Company, Middletown, Ohio, this month.

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L. W. Spring and **A. L. Boegehold,** members of the Editorial Advisory Board of METALS & ALLOYS have been selected by the American Foundrymen's Association, respectively, to present the 1931 exchange papers before the Institute of British Foundrymen and the European Foundry Congress, the latter to be held in Italy. The other 1931 exchange papers are by H. M. St. John, before the Association Technique de Fonderie de France, and by H. P. Evans, before the Bureau of Steel Manufacturers of Australia.

Microstructure of PEARLITE

BY H. E. PUBLOW* AND C. HEATH*

WE use many words glibly, and are prone to believe that we understand all about the things thus named. But when we stop to consider, we are really quite ignorant about many of these things. Metallurgists use the term "pearlitic structure" so frequently that most of them assume that there are no moot questions about that structure. That we do not know all we ought to know about pearlite, is brought out in the article below, which also throws some added light on the subject.

THE recrystallization changes which occur in iron and steel on being heated or cooled through the critical temperatures have long attracted the attention of both metallurgists and physicists. Far more study has been given to the effects of rapid cooling through the critical temperature than to the effects of normal, slow cooling, as it was considered that the latter was pretty well understood. There are, however, some phases of the transformations on slow cooling which might well be investigated. For instance, is pearlite a mixture of fine grains of ferrite and cementite, or does it consist of a crystal of ferrite subdivided by numerous lamellae of cementite?

Austenite is generally regarded as a solid solution of carbon or iron carbide in gamma iron and is crystalline in nature. When the temperature of this solid solution is lowered sufficiently it recrystallizes into two phases. This may also involve the formation of certain carbides of iron. Whether it does or not, the transformation must cause a tremendous upheaval in the crystalline structure, for it is accompanied by a considerable expansion of the metal.

Let us take, for example, low carbon steel. At a temperature well above the upper critical point, the metal will consist of a fairly homogeneous solid solution. At least each grain will be homogeneous, although the composition may vary from grain to grain. On cooling, no change takes place until the upper critical temperature is reached. According to the equilibrium diagram, when the temperature has fallen to the A_3 point, the solid solution begins to recrystallize, throwing out of solution a new phase, ferrite. This phase is not pure alpha iron, but a new solid solution of carbon in iron, containing a very small percentage of carbon. According to the diagram, the first particles or crystals of this new phase would be infinitesimal in size. Practically, however, nothing happens until the internal energy builds up sufficiently to overcome the inertia of the mass, thus the temperature where the change begins is lower than the A_3 point, or at the Ar_3 temperature. Since there is a sudden releasing of internal energy, the Ar_3 point is shown by a considerable evolution of heat, which becomes less as the temperature drops toward the lower critical point. By the time the latter is reached the remaining austenite has become saturated with carbon. Further lowering of the temperature causes this saturated solution to recrystallize into two phases, ferrite and cementite. The size of the crystals of these two phases depends upon the length of time allowed for this recrystallization.

Let us consider the decomposition of a single grain of austenite. When ferrite is produced from austenite by recrystallization, the type of crystal produced is entirely different from that which gave it birth. Carbon being only slightly soluble in this new phase, the carbon particles must migrate from their old position into the remaining austenite, or else be mechanically held in the newly formed ferrite. If the cooling rate is slow enough, practically all the carbon will be expelled from the ferrite into the remaining austenite. Apparently the ferrite, which is produced between the Ar_3 and Ar_1 temperatures, first forms in some definite portion of the austenite grain and not in minute particles all through the grain. If on slow cooling numerous particles of ferrite were thrown out of solution at the Ar_3 temperature, there would tend to form from each austenite grain a number of ferrite grains. Instead of this being true the size of ferrite grains seems to be governed in large measure by the size of the mother austenite grains. This, of course, does not hold true on rapid cooling.

As the temperature is lowered and the amount of ferrite increases, thus decreasing the amount of austenite, the latter becomes richer in carbon as this is the only place that the carbon can go and still remain in solution. The ferrite which is being formed is continuously changing in composition due to slight differences in the solubility of carbon in alpha iron at the various temperatures. This may mean that the ferrite might consist of many tiny crystals, submicroscopic in size, or possibly the mechanism of recrystallization may be such that the new ferrite grain is just one crystal. A large percentage of the impurities in the metal are located in the grain boundaries of the austenite, and since most of these impurities are as insoluble in ferrite as in austenite, their location during the recrystallization would tend to remain unchanged. On etching the polished surface of such a specimen, the boundaries of the old austenite grains would appear first. Thus, there is a possibility that the new ferrite grain which is produced on slow decomposition between the Ar_3 and the Ar_1 temperatures may consist of many small crystals, too fine to be distinguished under the microscope.

As the metal passes through the Ar_1 range, all the remain-

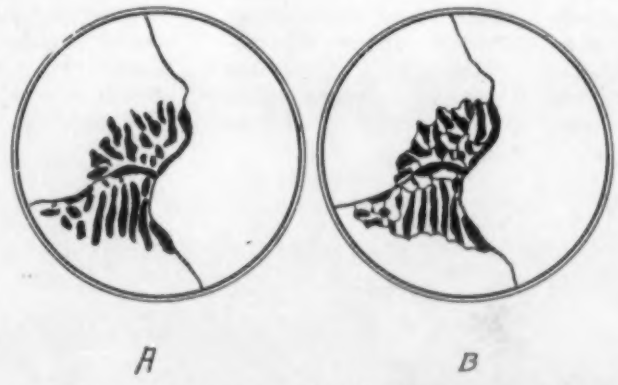

Fig. 1. Sketches of pearlitic areas showing two possible types of crystallization. A, showing the cementite particles in a ferrite matrix. B, showing fine grains of ferrite and cementite.

* Michigan State College.

Fig. 2. Low carbon steel with a light nital etch, apparently showing cementite precipitated in a matrix of ferrite. Mag. 2000×.

Fig. 3. Annealed low carbon steel showing a boundary separating the ferrite from the pearlite. Mag. 2000×.

Fig. 4. Annealed low carbon steel showing a boundary separating the ferrite from the pearlite. Mag. 2000×.

Fig. 5. Annealed low carbon steel showing a boundary separating the ferrite from the pearlite. Mag. 2000×.

ing austenite is decomposed into ferrite and cementite. If this decomposition has taken place slowly, the ferrite and cementite will separate out into two distinct phases. The old austenite grain has therefore been transformed into a new grain consisting of two phases, and which may consist of many new crystallographic units, only the outlines of the old grain remaining. Fig. 1 shows two possible grain formations. As shown in A, Fig. 1, it would mean that the cementite particles lay imbedded in a portion of the ferrite crystal. As shown in B, Fig. 1, the pearlite portion would consist of small crystals of ferrite and cementite. The pearlite would be separated from the adjoining ferrite by a grain boundary.

Fig. 2 is a micrograph showing the structure of low carbon steel at 2000 diameters. In this picture it looks as though the cementite particles lay embedded in a matrix of ferrite as shown in Fig. 1-A. If we etch the polished surface a little more carefully, so as to bring out the grain boundaries of the ferrite we find such structures as are shown in Figs. 3, 4, 5 and 6. In these pictures one can distinguish marked boundary lines between the ferrite and pearlite areas. In Fig. 6 a grain boundary can be seen passing through a pearlitic area. This means that in two austenite grains the pearlite areas formed next to each other, but did not merge together. In this series of pictures there are apparently no grain boundaries within the pearlite. Particularly in Fig. 3 it looks as though the cementite lay imbedded in a matrix of ferrite.

Several more samples are shown in Figs. 7, 8 and 9. These steels were heat treated so as to scatter the cementite. This scattering was done by reheating the slowly cooled steel to 1250° F. for several hours and slow cooling. The specimens were etched so as to bring out as many as possible of the grain boundaries. Since this semi-spheroidal cementite was produced by heating lamellar pearlite for a long period

Fig. 6. Annealed, low carbon steel showing a grain boundary separating two areas of pearlite. Mag. 2000×.

Fig. 7. Low carbon steel with scattered areas of cementite, showing grain boundaries in the ferrite. Mag. 2000×.

Fig. 8. Low carbon steel with scattered areas of cementite, showing grain boundaries in the ferrite. Mag. 2000×.

Fig. 9. Low carbon steel with scattered areas of cementite, showing grain boundaries in the ferrite. Mag. 2000×.

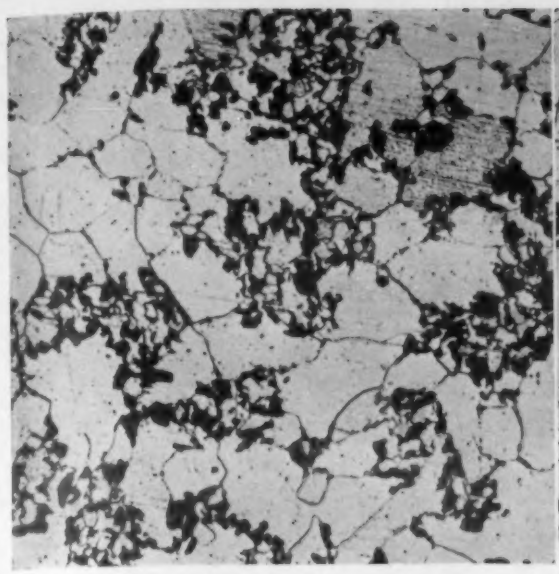

Fig. 10. Low carbon steel air cooled from slightly above the Ac_1 range. Mag. 100×.

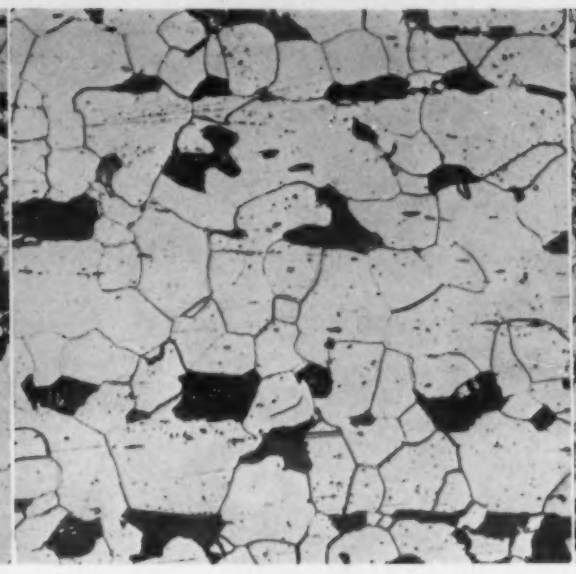

Fig. 11. Low carbon steel annealed at 1850° F. Mag. 100×.

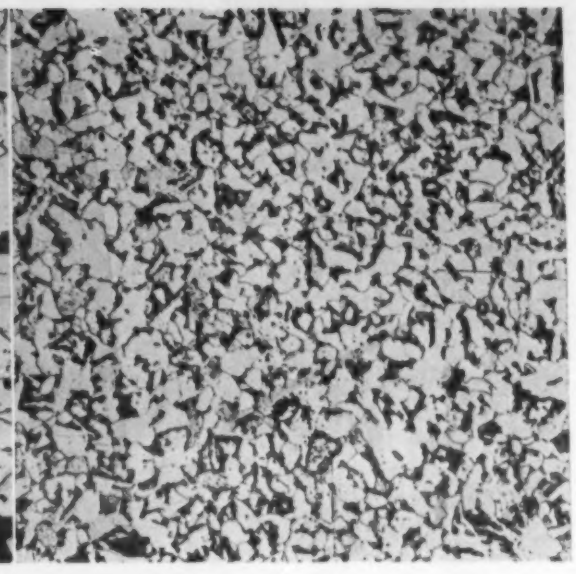

Fig. 12. Low carbon steel which has had the following heat treatments: Annealed at 1850° F. and having a structure as shown in Fig. 11, then heated to 1600° F. and slow cooled. This shows a considerable reduction in grain size. Mag. 100×.

of time below the lower critical temperature there must have been some inter-granular movement, the cementite locating in the grain boundaries of the ferrite. Pearlite then may possibly consist of small grains of ferrite and cementite, rather than a large grain of ferrite with cementite particles imbedded in it.

On reheating, the mechanism of recrystallization is somewhat different. On passing through the lower critical temperature the ferrite and cementite in the pearlite are transformed into a new crystalline mass of solid solution. As this involves a considerable movement of the atoms of iron and carbon, this solid solution of austenite upon being first formed probably consists of many small grains. If we cool a specimen of low carbon steel from just above the lower critical temperature, which before heating was in an annealed condition, we get a structure such as shown in Fig. 10. Fig. 11, shows the structure of this steel before heating.

On further heating more and more ferrite is transformed into austenite. This requires at the same time a movement of the carbon atoms into solution in the iron which is being transformed and therefore there must be a continuous recrystallization going on. If a sufficient time has been allowed for the solution to take place, by the time the upper critical temperature has been reached the newly formed austenite will consist of many small grains. If such a steel is cooled to room temperature, so as to allow normal pearlite to form, it will be much finer in grain than the original. Such a structure is shown in Fig. 12.

If we repeat the heat treatment again very little more refinement results, and after several heat treatments the grain size seems to reach a minimum. This is due to the fact that there is a lag between the criticals on heating and cooling which gives time for some growth of the austenite grains, even though cooling is started as soon as the Ac_3 temperature is reached. Due to this difference in mechanism of recrystallization on heating and cooling through the critical range we have a means of controlling grain size within certain limits in hypo-eutectoid steels by heat treatment alone.

Apparently then, there is a great deal to be explained regarding the transformations taking place on passing through the critical range of simple hypo-eutectoid steel even upon slow heating and cooling. If this change were better understood, it would probably clarify some disputed points regarding the structures produced in rapidly cooled steels.

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INDUSTRIAL CONFERENCES AT CASE

In an endeavor to bring together executives and engineers for the consideration of certain phases of engineering progress, Case School of Applied Science and The Cleveland Engineering Society last year started a series of Educational Industrial Conferences, held at Case, at which papers are presented by capable speakers followed by a general discussion of the subject by those interested. The intention is to acquaint those active in engineering and manufacturing development with the latest progress in some particular field in the hope that application of such knowledge will be stimulated.

In the Spring of 1931, three conferences were held—on Highways, Welding and Electrical Control in Industry—with considerable success. The conference on Welding had a registered attendance of 355, exclusive of Case faculty and students. Demonstrations of welding equipment drew much interest.

Plans for the academic year 1931–1932, include conferences on the following subjects:

Metals and Alloys—November
Air Conditioning—January
Industrial Fuels—March

The conference on Metals and Alloys, scheduled for November 18th, 19th and 20th, will be arranged to appeal to three groups:

1. Architects and structural engineers—treating the use of alloys in building and decoration.
2. Power and process engineers—treating the use of alloys requiring resistance to corrosion, high temperature, wear, fatigue.
3. Design and product engineers—treating the use of alloys in the manufacture of machines, aircraft and other products. This would include high strength, light weight alloys, bearing alloys, cutting alloys, hard alloys, etc.

There will be overlapping of interests in the various groups, and an effort will be made to bring common interests together on the program.

Fully qualified speakers will be selected with no limitation upon affiliation or location. Demonstrations and exhibits of specimens and equipment will be conducted in the laboratories. These will include complete die casting process with physical tests, and X-ray examination; welding of special alloys; architectural and structural alloys; physical and metallurgical tests on and exhibits of light-weight alloys, stainless steels, "monel metal," "brass," "nickel silver," etc.; exhibits of alloys with special properties for endurance, corrosion resistance, wear, hardness, etc.

At left, a battery of Homo normalizing furnaces. At right, a battery of Homo heat treating furnaces. (Leeds & Northrup Co.)

MODERN

BY RICHARD

DO YOU have a furnace or oven in your plant performing a metallurgical operation? Have you forgotten that furnace located back in the corner of the shop or in that lean-to put up in an emergency some years ago? Is it doing a good job? Have you questioned the capacity or efficiency of the installation, in comparison with that of your competitor?

Check up on the old furnace and you may discover how to improve the quality or greatly reduce the cost of the operation. Ask yourself the following questions: Are you using the most economical fuel? Can you use recuperators? Will mechanical operation and automatic control eliminate the human element? Do you have sufficient furnace capacity? Are you constantly replacing certain parts? Can your operation be made continuous? Is your floor space limited? Do you have a record of furnace operation? Can more than one operation be combined in a single unit? How can this process be improved and its cost reduced?

An answer to these vexing questions, directly applicable to your conditions or so nearly so as to require little modification, almost certainly exists. Many minds have been working on these problems in recent years. Over and over again, furnace engineers have designed specific furnaces for various operations producing uniform results with high efficiencies.

Some outstanding installations in furnace design and practice are briefly described and illustrated below. The list might be very greatly extended, and these are chosen merely as examples that show what can be accomplished by installing modern equipment and up-to-date operating control.

Vertical Continuous Rod and Tube Hardening Furnace (American Electric Furnace Company)

The furnace is of the regular pit type construction with a multiple retort. These retorts are charged at intervals depending on cross section of material, and are controlled by a clock which operates on a range as low as five seconds. The furnaces are 90 kw. rating with over-lapping three zone control, each zone 3 phase, 230 volts. The eight retorts in each furnace are approximately 4 inches diameter by 6 feet deep, and rotate on ball thrust and roller bearings. The retorts are charged at the top and, when the cycle is complete, discharge automatically into quench. The quenching bath is continuously circulating, and is both cooled and then electrically reheated before entering quench tank, so that a uniformity within 5° F. is constant. This very close quenching control has been found necessary on high carbon thin sections, like a steel golf shaft where the least difference in grain structure is disastrous. Each furnace has a continuous production capacity of nearly 800 lbs./hour, and is being operated on a 24 hour basis.

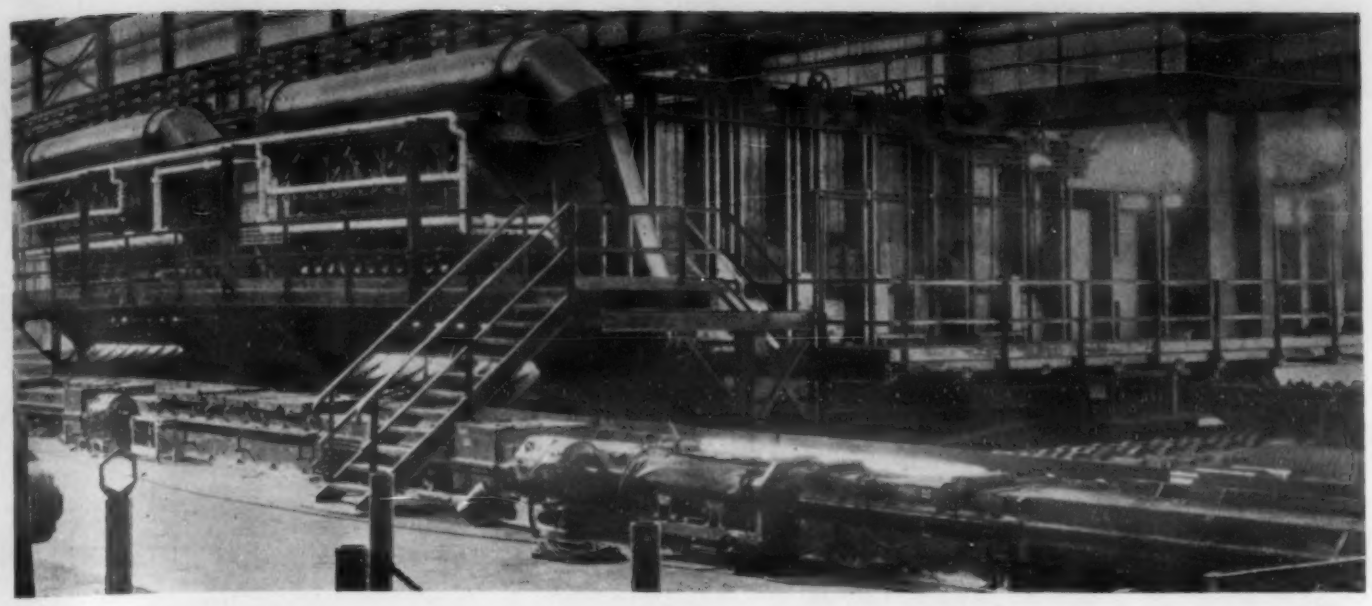
Electric Lavite Furnace for Silver Annealing (Bellis Heat Treating Company)

Heating the bath by its own resistance is a new feature in salt bath furnaces. The current is led to the furnace through metallic conducting electrodes and the heat is generated within the bath rather than applied externally as heretofore. The pot is 7 feet long by 2 feet wide by 2 feet deep and operates at 1350° F. and has a capacity of 3500 lbs. of silver per hour with the cover off 25% of the time. An evaporator

A HEAT TREATING or similar furnace used to be just a furnace—a pile of bricks and a burner. Nowadays it is a machine, designed to produce whatever temperature-time cycle is required by the work in hand, and with a minimum of labor and attention.

Any good machine generally produces more uniform results than any good workman using hand methods can. It is this need for uniform high quality at a rapid production rate that has mechanized the quantity heat treatment game. The labor saving is important, of course, and the better thermal efficiency of a properly designed furnace cuts the bills for fuel or electricity, but those savings would seldom show a big profit over the old methods if there were the same percentage of rejections.

The mechanized furnace shines by its ability always to do the same thing in the same way.



Heating furnaces for 32 inch strip mill. Each furnace has a capacity of 40 tons per hour. (Chapman - Stein Company.)

FURNACES

RIMBACH

recovers the salts dissolved in the quenching tank, reducing the operating cost.

The practice is to charge 750 lbs. of silver in the furnace for 5 minutes then, after rapidly quenching and rinsing, it is ready for the next rolling operation in 12 minutes whereas former annealing required more than an hour. The quality and uniformity of the annealing are contributory to the reduction of power required for rolling. A more recent installation, with a larger pot and 250 KVA rating, handles 4000 pounds per hour in 900 lb. charges in 12 minute cycles.

Continuous Forge Furnace (Costello Engineering Company)

The furnace is used to heat small blanks continuously which are forged under a steam hammer. The blanks are pushed through the furnace by means of an oil hydraulic pusher. The pusher, oil pump, motor and small storage tank are combined in a self-contained unit.

The hearth is constructed of a plastic chrome refractory with a series of "V" grooves extending the length of the furnace. The square stock is pushed through these grooves laid end to end. Burner equipment is so designed and arranged to give the longest possible flame travel. The gas and air are both delivered under positive pressure so that a given fuel air ratio can be maintained under any pressure condition existing in the furnace.

Automatic temperature control also operates the dampers providing the escape of waste gases in proper proportions to maintain a neutral atmosphere in the furnace.

Heat Treating Oven (Despatch Oven Company)

The Type H air drawing oven enables air drawing and tempering quickly, uniformly and economically. It is designed for all low temperature heat treating and air drawing requiring a maximum temperature of 800° F.

The oven is of the double wall type. Between the heavy steel walls are 5 inches of high grade insulation holding the heat losses to a minimum. A third wall or lining forms the interior working chamber, providing an air space between the second and third walls. At the top of the oven is a vertical motor and fan, and in the bottom is the gas heating system.

The purpose of the third wall is to form a baffle so that the heated air may rise to the top of the oven without entering the working chamber. This flow of air to the top of the oven is accelerated by the fan, which forces the heated air down on the parts in the chamber which are being treated.

On each side near the bottom of this inner wall are slots through which the heated air leaves the working chamber and is mixed with air rising from the burners and is again raised to the proper temperature upon reaching the fan at the top. Recirculation means a great saving in gas, for instead of heating the air from room temperature to that required for the tempering process, it is only necessary to raise the temperature of the recirculated air 5° to 10° F.

A special fan forcing the heated air down on the work uniformly, permits a guarantee of ±5° F. variation in the working chamber. Further assurance of uniformity is furnished by a vapor tension thermostatic control system operating in conjunction with a relay and motor driven valve in the gas supply line insuring positive control.

If, then, the metallurgist correctly chooses his steel or other alloy and controls it for uniformity and then purchases that type and make of furnace-machine that will without fail give the temperature-time cycle he must have, the parts come out uniform as to properties and machinability, and rejections drop to such a point that it may well mean for his firm the difference between red and black.

Even when the metallurgist is not so fortunate as to be called upon for quantity production that would justify complete mechanization, the same general principles hold for smaller scale, batch operations. Design that makes for uniformity of heating, automatic temperature control and continuous records, together with better thermal efficiency, can be had in modern furnaces and will vastly help in lowering rejections and lowering costs.

Tunnel type annealing kiln. (Swindell Dressler Corporation.)

Oil Fired Continuous Forge Furnace (Electric Furnace Company)

This forge furnace has a grooved hearth permitting the handling of various sizes and lengths of rounds and squares with ease. There are eight rows of stock in the furnace, each pushed by individual pusher heads of the cam and lever type, allowing individual discharge alternately from each row.

The furnace is elevated on structural steel supports—the work is discharged through a slot in the bottom of the furnace and conveyed by a chute to the hammer operator.

An increase of production of 100% over that produced with a conventional slot type furnace and a saving of over 50% in fuel are claimed. Accurate temperature control has entirely eliminated overheated material and scaling is reduced to a minimum.

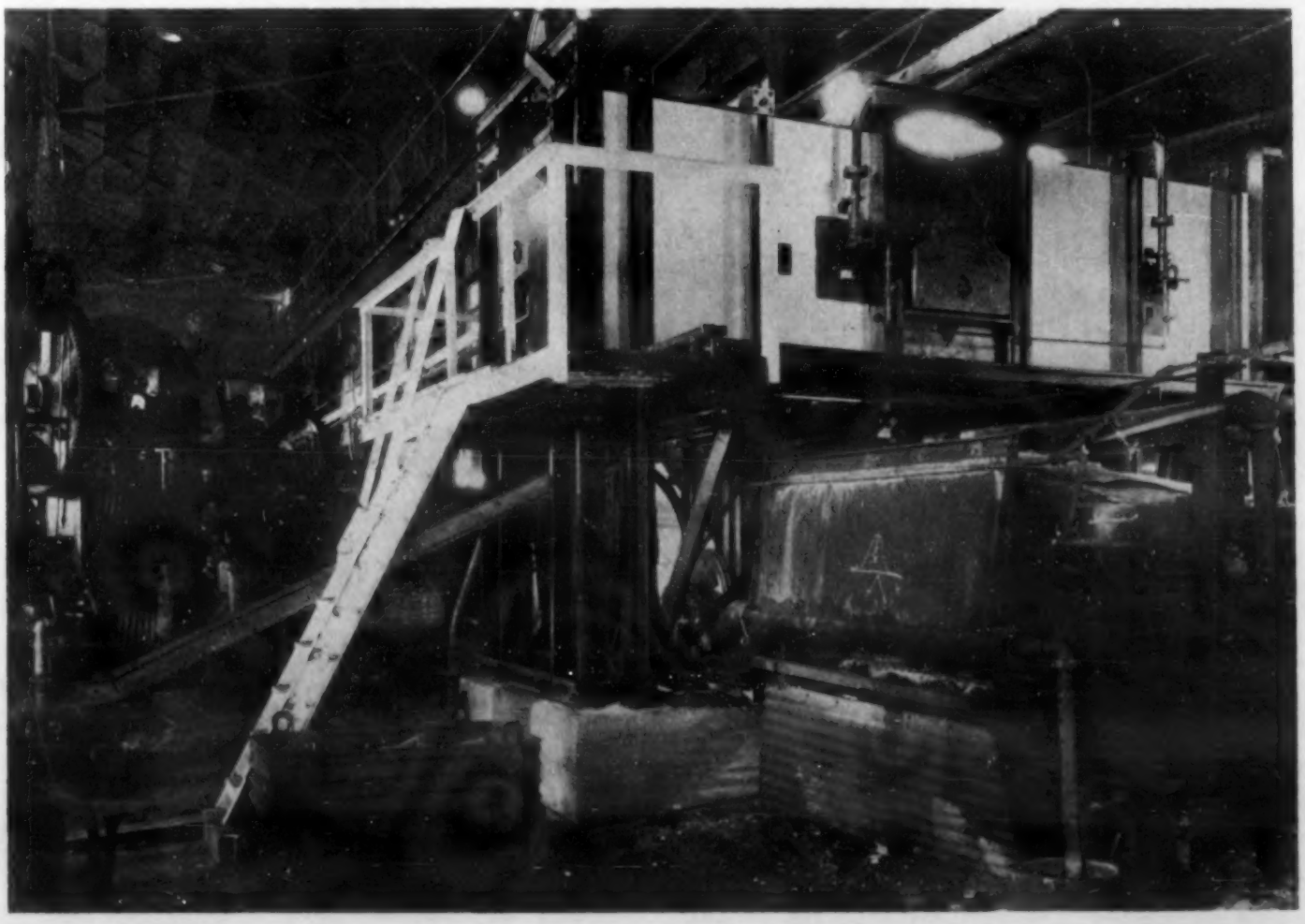
Vertical Continuous Enameling Furnace (Ferro Enamel Corporation)

The vertical continuous enameling furnace is developed to combine the economies of continuous operation in a smaller sized production unit, together with low maintenance, less floor space, greater accessibility and higher firing efficiency. The principle of the vertical furnace operation is to provide a convenient loading and unloading place and to have the fusion take place in an enclosed chamber convenient to the loading place, but enough removed to allow cool working conditions.

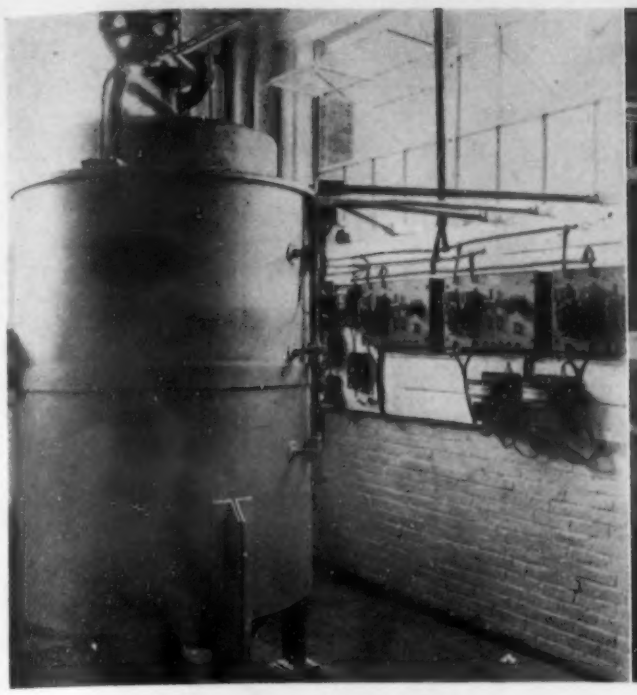
The ware is carried on burning tools mounted between parallel conveyor chains guided by sprockets, attached to the steel shafts. The burning tools project downward from the chains at all times; being free moving, the ware is always in the vertical plane.

The ware is loaded on the tool on the lower chain traveling away from the furnace, over the sprockets, attached to the drive unit of variable speed, then back into the preheater which is above the outgoing burned ware, absorbing the heat from the tools and ware coming from the firing zone. From the preheat zone, the ware passes upward into the firing chamber, a vertical, insulated and sealed shell, containing the heating medium, then downward to the cooling zone.

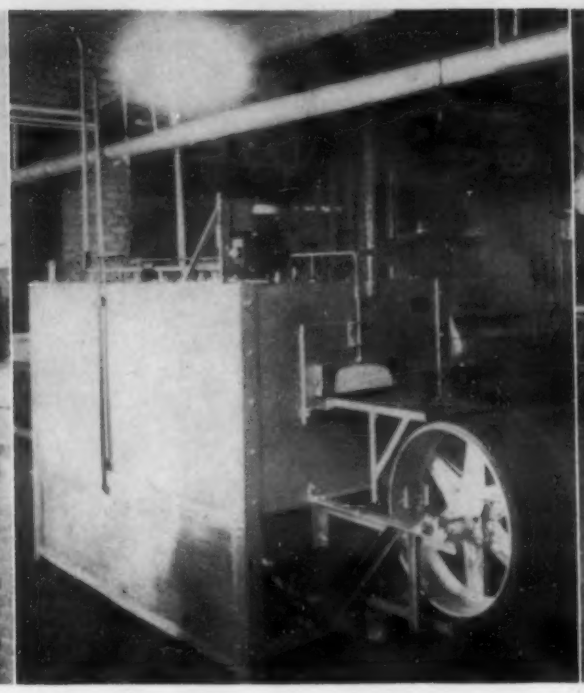
The only moving parts in the firing zone are the tools, chains and ware, the sprockets being outside of the furnace. Throughout the system there is an exchange of heat from the work leaving the firing zone to that entering, giving a slow heating and cooling of the ware. Slow heating minimizes warpage of the metal and subsequent chipping of the enamel.



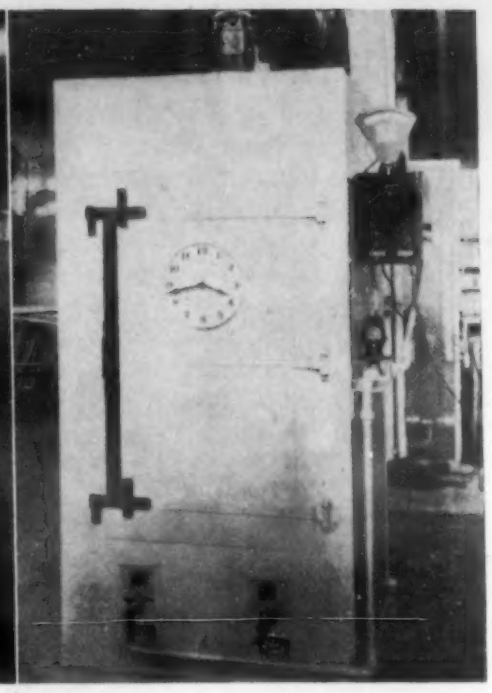
This illustration shows old and new methods. An old slot type forging furnace is shown in the foreground. An oil fired continuous pusher type billet heating furnace is shown in the rear. (Electric Furnace Company.)



Vertical continuous rod and tube hardening furnace. (American Electric Furnace Company.)



Bright annealing electric conveyor furnace. (Process Engineering & Equipment Corporation.)



Drawing oven. (Despatch Oven Company.)

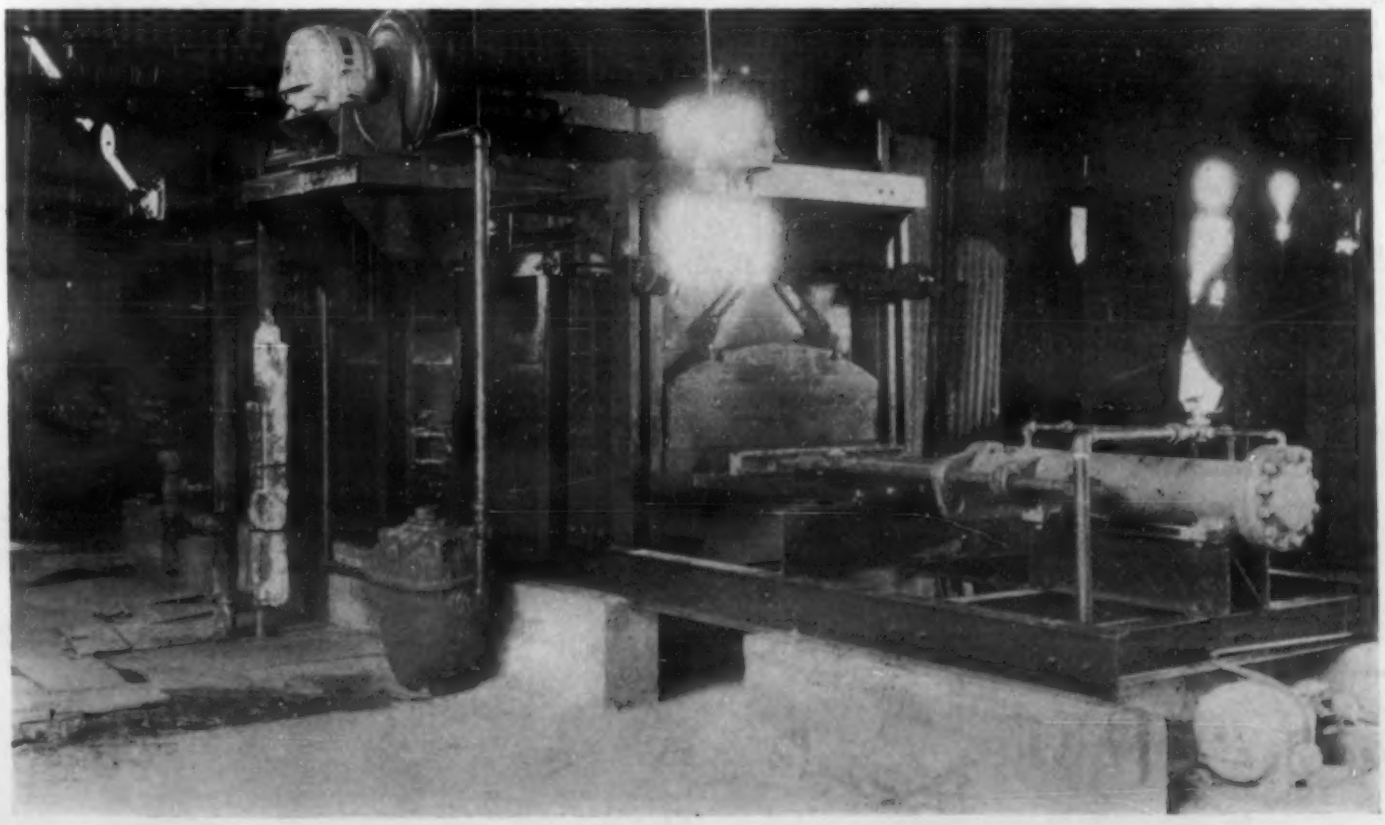
Electric High Speed Steel Heat Treating Furnace (C. I. Hayes, Inc.)

This installation consists of a preheating furnace operating at temperatures around 1600° F., and a furnace for hardening at temperatures up to 2400° F. Both furnaces are equipped with the attachment for controlling furnace chamber atmospheres to prevent scaling and decarburization. The method consists of introducing combusted gases into the working chamber in such a manner as to form a transparent curtain of combusted gases across the throat opening, and also filling the furnace chamber, displacing all oxygen bearing atmosphere and preventing entrance of oxygen from the outside. The volume of the curtain is increased as door is opened and decreased when door is closed. An arm and lever attached to door operating mechanism operates a by-pass valve which accomplished this result automatically. In the operation of this control the furnace operator has complete control and can adjust the atmosphere according to requirements. By varying the proportionate amount of air and gas a very rich or very lean mixture can be maintained which has a distinct advantage in its relation to producing various structural conditions in the steel.

Vertical Retort Carburizing and Nitriding Furnace (The Hevi Duty Electric Company)

The Hevi Duty electric furnace, of the vertical retort type, for both carburizing and nitriding processes, when applied to carburizing uses Carbonal, a special liquid blended to produce when vaporized a gas high in hydrocarbons, as a carburizing medium. The Carbonal is introduced into the hot furnace retort by a drip feed attachment, being immediately cracked; nascent hydrocarbons are released which react on the surface of the charge. Unused or excess gases are vented.

In the cover of the retort is a motor-driven centrifugal fan



Continuous forge furnace. (Costello Engineering Company.)

for circulating the hot gases, assuring uniform penetration to all parts of the charge. Labor required for packing, as well as carburizing compound, have been eliminated as contact of parts does not have any effect upon the case. The time of heating up to the carburizing temperature is reduced approximately one-half as no box or compound is required. For a depth of case of 12 to 15 thousands on SAE 1020 steel the carburizing time has been reduced one hour. Uniform case depths and carbon content are found throughout the charge. The carburizing temperature is somewhat lower than when using compound.

Homo Electric Heat Treating Furnaces (Leeds & Northrup Company)

Twenty Homo furnaces are in this installation for both normalizing and final heat treatment of bolts and rivets. In normalizing upset products it is necessary to relieve all forging strains before subsequent heat treatment, requiring a close range of temperature as well as proper furnace atmosphere to prevent scaling. The batch type furnace is especially adapted for bolts and rivets as there is need for flexibility due to the great variety of sizes and grades. The bolts are not jostled, preventing battered threads and bent bodies.

A batch of work in a cold Homo furnace takes only half an hour longer to come up to temperature than when the furnace is hot.

Continuous Cleaning, Dipping and Baking Oven (Paul Maehler Company)

This equipment was installed for high production handling of brake drums, parts and housings for "Midland" automobile brakes, automatically cleaned and coated in a continuous line. The method of handling is by hooking parts to a two strand bar flight conveyor, running 5 ft./min. through successive sequences of load, cleaning, drying, cooling, dipping, draining, baking, cooling and unloading.

Machines of this type are designed to clean by pressure velocity rather than boiling water temperatures. The water is carried at 150° F. and is delivered through a 600 g. p. m. recirculating pump at 35 lbs. pressure rain spray above the work in transit. The pass through the washing machine provides only three minutes of time, traveling horizontally; the work then passes immediately into a two pass vertical drying section built of a 3″ insulated sectional panel and heated to 400° F. from a high-pressure gas burner thermostatically controlled. The work is conveyed, therefrom, through an air locked opening into the cooling, dipping and draining section.

The dip tank contains 450 gallons of black japan, and complete draining is accomplished in 10 minutes. After draining the work proceeds into an air locked sectional panel type oven insulated 4″ thick on all surfaces. The conveyor loops are of the multiple pass type, making seven vertical passes, which provides 90 feet of travel in an oven 17 feet long.

The oven is heated by a recirculative-incinerative type direct gas fired heater to 450° F. An insulated recirculating duct system exhausts the vapors, given off by the work, to the body of the heater and through its burner to the oven, insuring a constant circulation of oven atmosphere through the heater approximately five times per minute.

The heater is a double steel jacketed type with a single low pressure section burner fitted with a double steel housed and insulated high temperature fan.

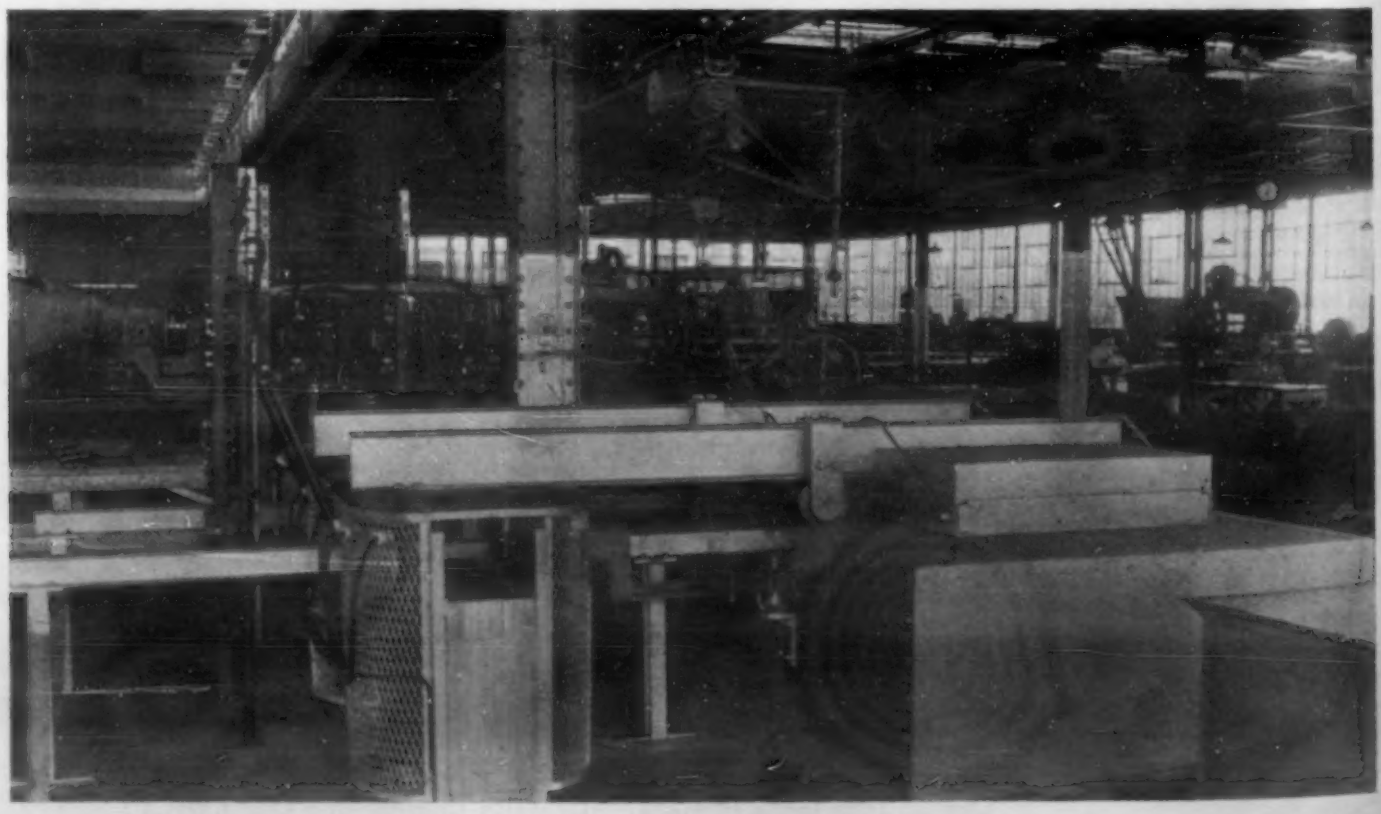
Safety equipment is provided for fire, current failure, insufficient fuel pressure and failure of supply fan to function. A visible pilot is provided with spark plug ignition, controlled by an intensifier and a motor operated actuator timed at five second intervals.

Bright Annealing Electric Conveyor Furnace (Process Engineering & Equipment Corporation)

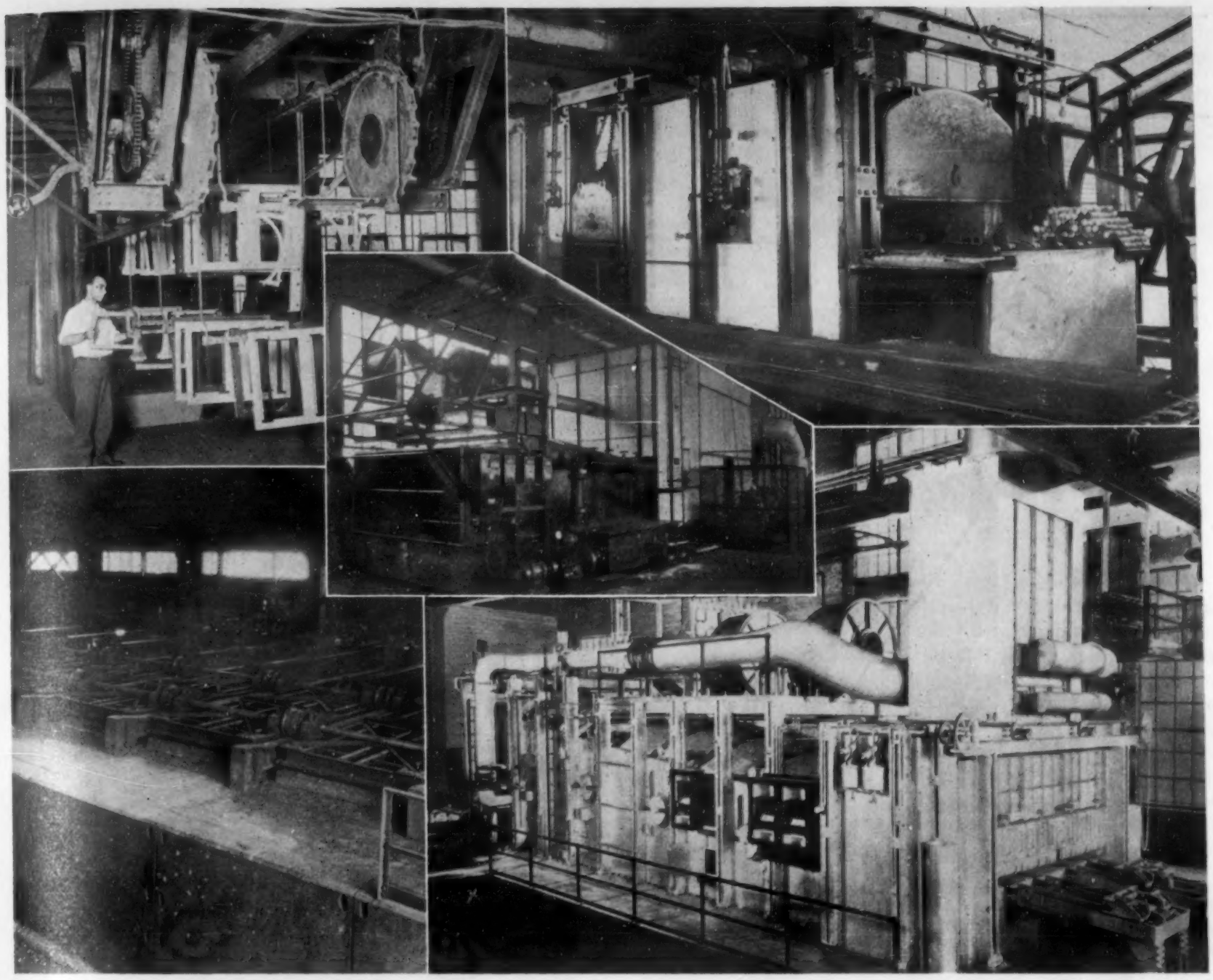
The furnace is of a variable speed continuous conveyor type, having a belt width of 12 inches and a heating chamber length of 72 inches, and will bright anneal 600 lbs./hour of brass or nickel silver blanks or stampings. The material is placed directly on the conveyor belt and moves through the heating chamber, with annealing conditions of temperature, time and furnace atmosphere, automatically controlled. The material comes from the cooling chamber bright, clean and dry, ready for succeeding operations without tumbling, pickling or cleaning. Additional economies were secured in reduction of stamping operations, direct labor and increase in die life with lower polishing costs.

Continuous Copper Billet Heating Furnace (Ryan, Scully & Company)

This furnace in many ways represents a radical departure from the ideas and types of construction heretofore associated with the heating of copper billets. It is oil fired and is of the two row split flame type. The normal capacity is heating 60,000 lbs./hour of cast copper billets weighing 250 lbs. each to 1750° F.



Lavite high speed steel hardening furnace. (Bellis Heat Treating Company.)



(Upper left) Vertical continuous enameling furnace. (Ferro Enamel Corporation.) (Upper right) Charging end of oil fired continuous automatic grooved hearth pusher type billet heating furnace. (Electric Furnace Company.) (Center) Continuous cleaning, dipping and baking oven. View from loading end. (Paul Maehler Company.) (Lower left) One-way fired soaking pits. These pits have been largely responsible for the adoption of the one-way fired principle as opposed to the old method of reversed firing. (Surface Combustion Company.) (Lower right) Continuous copper billet heating furnace. (Ryan, Scully & Company.)

There are 10 low pressure recuperative type oil burners, 5 located at the extreme back end of the furnace firing over the tops of the billets, while the other 5 fire longitudinally under the billets, between the piers supporting the skid rails, permitting the billets to absorb heat from the hot gases which completely surround them.

Air for combustion is preheated in a recuperator to 400° F. and carried to the burners in insulated pipes. Provision is made for preheating the oil if necessary. Automatic temperature and pressure control, divided into two zones, is used. One unit controls the operation of the top burners while the other controls the lower burners. The control valves are specially fitted for controlling preheated air and are equipped with valves for operating the stack dampers automatically. Fuel consumption averages $5^1/_2$ gallons of oil/ton of copper heated on a 50% capacity operating schedule.

As it is essential in heating copper billets to maintain a slightly oxidizing furnace atmosphere a 2 point CO_2 recorder is used to assist the operator in the setting of the control valves and dampers.

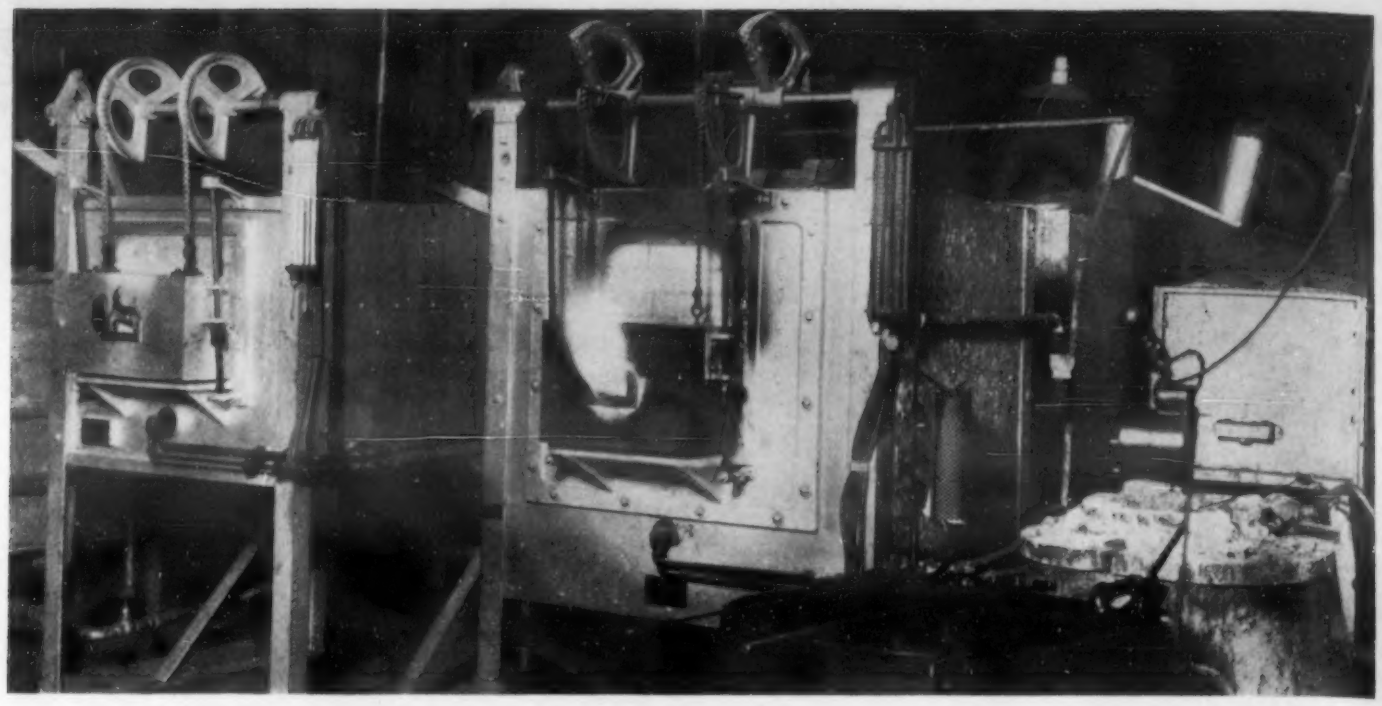
There are heat resisting alloy skid rails and guides along the side walls and between the two rows of billets. The billets are pushed through the furnace in two rows by means of straight line pushers operated by oil gear pump and cylinders working alternately so as to give a constant discharge.

One Way Fired Soaking Pit Furnace (Surface Combustion Company)

This furnace is as its name implies non-reversing and is fired through burner ports located at one side toward the top of the pit holes and the waste gases are taken out of ports located in the same side walls toward the bottom of the pit. In place of regenerators in the pit, Chapman-Stein refractory tile recuperators are used. Coke oven gas is the fuel used in installation shown. Other fuels can also be used. The fuel is admitted to the pits direct while the air for combustion is heated to about 1000° F. after passing through the recuperators. The features of this type furnace are: uniform heating, small floor space, simplicity of operation, low maintenance, low fuel consumption and scale condition of the ingots.

Continuous Billet Heating Furnace (Surface Combustion Company)

Two continuous billet heating furnaces recently installed serve a 32-inch strip mill. Each furnace is 18 feet wide inside the brick work by 60 feet effective length and is rated at 40 tons/hour. The billets are charged into these furnaces at one end and carried through on water cooled skids up to a point about 12 feet from the discharge slope, where they are carried over a soaking hearth to remove the skid marks and soak the steel. They are discharged by gravity on to the roll table.



Electric high speed steel heat treating furnace. (C. I. Hayes, Inc.)

The furnaces are oil fired with three sets of burners. One set is located below the skids for heating the steel before it reaches the soaking hearth. Two sets of burners, one directly above the other, are located in the firing chamber above the steel—the top set for heating the steel back in the furnace while the lower set controls the temperature in the soaking hearth.

Oil burners, mechanically atomizing, are used, eliminating the cost of pressure air or steam. The furnaces are equipped with Chapman-Stein refractory recuperators located below the hearth and are of the natural draft type.

Tunnel Type Annealing Kiln (Swindell-Dressler Corporation)

The Dressler tunnel type annealing kiln is 182 feet long, holding 22 cars of 18 pot capacity or approximately 9000 lbs. of castings per car. When a loaded car is pushed in, a finished car is pushed out the opposite end by means of a 100 ton hydraulic ram. When operating at capacity, a car is pushed in every $5^1/_2$ hours, making a complete cycle in 120 hours, producing about 20 tons of annealed castings every 24 hours.

There are three heating zones in the kiln. The first is maintained at 1700° F. for heating. In the second, or intermediate cooling zone, which is cooled by omission of insulation and the construction of special flues, built in the sides of the oven, the temperature is allowed to drop from 1700° to about 1400° F., quite rapidly. In the third or final cooling zone, the temperature is held at about 1400° F. for about 20 hours by use of auxiliary burners after which it drops again quite suddenly to about 1000° F. when the car is removed.

The kiln is fired with washed gas of a B. t. u. value of about 160, made from buckwheat size anthracite coal which is fed mechanically into a gas producer.

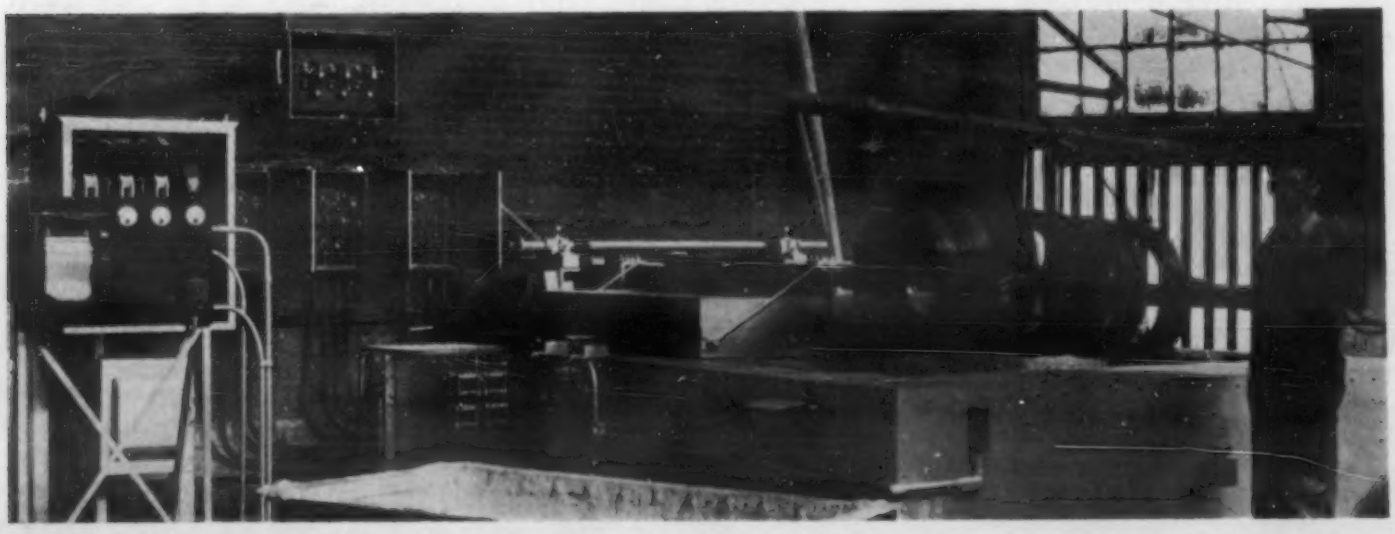
Outstanding feature of the tunnel type kiln is the accuracy to which temperatures, both heating and cooling, may be controlled, resulting not only from efficient construction and equipment of the kiln, but because of the lesser cross-section of the source of heat, which reduces serious temperature lags to a minimum. The pots are protected from the atmosphere of combustion as the heating zone is muffled from the combustion chambers and the actual heating is by induction of heat through specially constructed walls.

Sheet Mill Furnace (Wean Engineering Company, Inc.)

To modernize sheet mills the Wean Engineering Company, Inc., developed continuous pack heating furnaces that would heat at a higher rate and discharge the material without physical labor. The important features in the furnace are the use of a small number of large burners and the firing by means of a "Radiant Gap" construction which is so designed as to circulate hot gases around the material instead of throwing the flame from the burners directly into the furnace chamber.

A pair furnace identical with the pack furnace has been introduced to permit similar econo nies on the rough mill. In addition these furnaces have sufficient flexibility to permit the producer to use conventional bar, wide thin bar, termed break down bar or plate strip for breakdown purposes.

Mechanical feeders and catchers on both the rough mill and finishing mills together with a continuous hot mill polisher for the rolls make it possible for the sheet mills to compete with the wide strip mills.



Electric Lavite annealing furnace. (Bellis Heat Treating Company.)

Keeping DURALUMIN Rivets Workable with DRY ICE

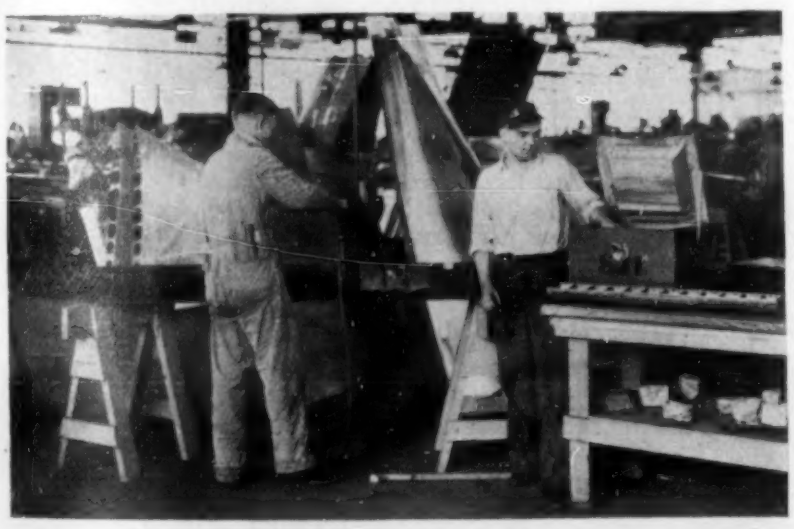
BY E. P. DEAN*

THE fact that there is, at room temperature, but a brief period subsequent to quenching but prior to aging, during which the mechanical properties of duralumin are ideal for forming operations, has led to considerable experimentation† on the retarding of the age hardening of duralumin in order to protract its useful formative period, by using ice to keep it cold.

The Boeing Airplane Company of Seattle has recently demonstrated the use of "dry ice" (solid carbon dioxide) as a convenient method of retarding the aging. The tests have shown a material saving of time and expense.

Metals, particularly duralumin, are being increasingly used in the construction of airplanes of the Boeing Airplane Company, and consequently the development of this use of "dry ice" is regarded as extremely important.

To be effective, duralumin rivets had formerly to be used within a fifteen-minute period directly following the heat-treating and quenching. The rivets are heat-treated in molten salt at a temperature of 950° F. Formerly, therefore, it was necessary that the duralumin heat-treating unit of the plant be in continuous operation, and that boys constantly



This photograph shows a dry ice box in use in a section of the Boeing's sheet metal department where a dural aileron is being assembled by riveters.

supply riveters with fresh rivets, returning the old rivets which had passed the fifteen minute limit, for re-treating. When riveting work was necessary at the company's hangar, located at some distance from the factory proper, the problem of transmitting fresh rivets from the heat-treating plant to the hangar at frequent intervals was difficult.

Immediately following the heat-treating and quenching, the rivets have only about the hardness of annealed duralumin. Within a comparatively few minutes after quenching, age hardening begins, and after a maximum period of thirty minutes, the rivets become so hard that they split when used.

A test was made with sample 1/8-inch rivets. These were heat-treated, quenched and immediately cooled to a temperature of approximately 10° F. After an entire week at this temperature, examination showed that the rivets had not aged appreciably, and they hardened only slightly after a two-weeks' interval.

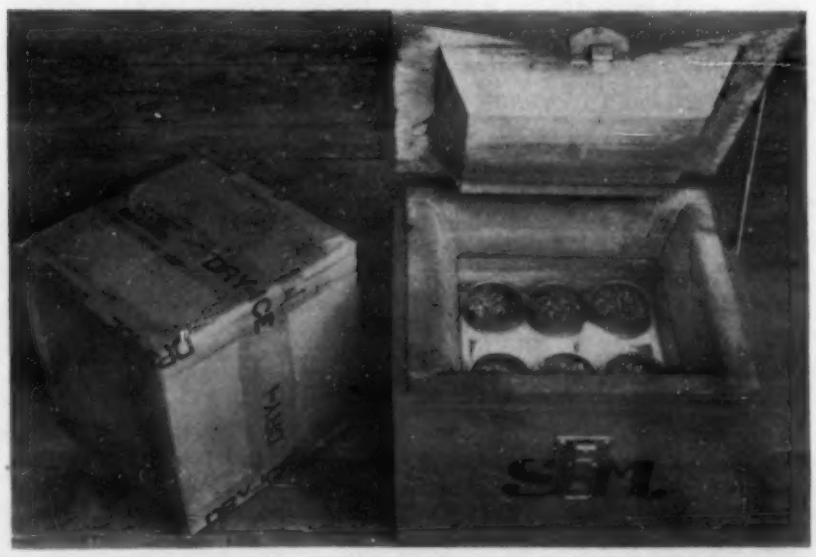
Boeing Airplane Company selected "dry ice" as a refrigerating medium instead of ice water as used in experiments elsewhere. Rivet boxes were specially constructed with interior dimensions of 9 by 11 inches and 5 inches deep. Around this was placed a 3-inch layer of balsa wood for insulation, and the whole was housed in a shell of 3/4-inch fir plywood. A small compartment was fabricated of screen for the "dry ice" and screen trays were installed for the rivets. Screens were used to permit effective circulation of the cold. Ten of these boxes were constructed, as well as a larger master storage box, and these are now in use.

The "dry ice" is wrapped in paper before being placed in the box for the reason that the ice without wrapping creates a temperature lower than necessary. The average temperature in the box is approximately 30° F.

Each morning, the Boeing heat-treatment department prepares an adequate number of rivets to supply all departments in the plan for the day. Immediately after quenching, these rivets are distributed in the boxes to the various departments.

At the present time, riveting is being conducted in the brazing department, the machine shop, the wing room, the final assembly department and, occasionally, the hangar. Of course, the major share of the riveting is confined to the sheet metal department.

Considerable reduction of the expense was reported, with only 100 pounds of "dry ice" required weekly for the rivet boxes.



This photograph shows the dry ice box developed by engineers of the Boeing Airplane Company for the storage of heat-treated dural rivets. The use of this refrigeration permits heat-treated and quenched rivets to be kept over a period of hours before being used without being affected by age hardening. The low temperature arrests this hardening which otherwise prevents the rivets from being used after a half hour following heat treating. The box is lined with balsa wood and the rivets are placed in screen trays to permit effective distribution of the cold.

* Boeing Airplane Company, Seattle.

† Compare, K. L. Meissner. Einfluss des Lagerns in Eis auf die Veredelung von Duralumin. *Metallwirtschaft*, Vol. 9, Aug. 1, 1930, pages 641-642; and E. H. Dix, Jr. and F. Keller. Experiments on Retarding the Age Hardening of Duralumin. *Paper before Institute of Metals Division, American Institute Mining and Metallurgical Engineers*, Sept. 1930.

The Story of the NICKEL INDUSTRY

BY A. J. WADHAMS

A. J. Wadhams*

THE discovery of nickel ore near the village of Orford, in the Province of Quebec, Canada, marked the beginning of the present The International Nickel Company of Canada, Limited. The attention of W. E. C. Eustis, a Bostonian interested in mining and metallurgical processes, was drawn to this mine and late in 1877 he bought it from Robert G. Leckie, a Scotch mining engineer. To develop the property Eustis secured the services of Leckie on mining, John L. Thomson on smelting, and with Henry M. Howe as manager and consulting engineer, organized the Orford Nickel Company.

From the start the ore was very refractory and great difficulty was experienced in smelting. Finally some ore from an adjoining mine, containing copper sulphide, was secured and a satisfactory matte produced. This led to the purchase of the Crown Mine at Capleton, later known as the Eustis Mine. R. M. Thompson, a young Boston lawyer, was engaged by Eustis in connection with the mining venture. Thompson had graduated from the U. S. Naval Academy in 1868 and after a few years at sea had resigned from the Navy to study law at Harvard. Young Thompson went to England for his Boston client, his instructions being to negotiate a lease of the mine. Deciding that it would be more profitable to purchase than lease the property, he proceeded to do so on his own responsibility. The directors were somewhat surprised but approved his action and made him general manager, Howe having gone to Chile to be away about a year. A new company was formed in July 1878, becoming the Orford Copper & Nickel Company. From this time on Thompson occupied himself with mining, smelting and refining, and left the practice of law to others.

As the work continued the Orford nickel ores were discontinued and all effort centered on the Eustis Mine at Capleton. The matte was sent to Swansea, South Wales. Some difficulty was experienced in disposing of it at a satisfactory price, which led to the building of the smelter at Bayonne, New Jersey.

Orford Copper Company

In 1881 Thompson went to New York to look for a suitable site for a smelter to treat the Eustis copper ore. On January 31, 1881, four acres of sunken meadow at Bayonne were purchased. At this time the City of New York was towing ashes and rubbish several miles to sea for dumping. Thompson got them to agree to dump the rubbish on the sunken meadow. By this method he secured for his company a valuable site for a smelter on tide water in New York Bay.

Henry M. Howe, known in later years as one of the foremost mining engineers and metallurgists in the land, had returned from Chile and was soon busily engaged building a smelter on the filled land. Dr. E. D. Peters, who in later years became a recognized authority on copper smelting and refining, and Professor of Metallurgy at Harvard University, was his assistant. John L. Thomson came from Capleton to manage the furnaces. An adjoining works, making sulphuric acid for the Standard Oil Company, was persuaded to use the sulphur from the Eustis Capleton ore and return the cinder containing copper and iron to the smelter, which took the name of "Orford" from the parent company.

For some time work on the Capleton ore went along in good shape. Soon copper ores began to appear for refining on the Atlantic Seaboard from mines in the West and before long the use of ore from Capleton was discontinued, and Eustis and Thompson parted company.

With the assistance of a loan from W. A. Clark, Thompson took over the Orford Works and further consolidated his relation with W. A. Clark and his brother Ross Clark by setting up a smelting

First smelter at Copper Cliff

furnace in Butte, Montana. Ore was smelted at Butte and the copper matte brought to Bayonne, N. J., for refining.

Before long the well-known "Secretan Affair" brought Thompson an unexpected windfall. Agents sent by the French Syndicate to purchase the large copper smelters in the United States found their capital insufficient to carry through the program. Before the scheme collapsed they had taken an option on the Orford smelter. The syndicate made a contract for control of the Orford plant, agreeing to furnish a large amount of copper per month, to be refined on delivery. It was stipulated that if they

* Manager, Development & Research The International Nickel Company of Canada, Limited.

did not make this delivery they would be liable for damages. Saturday the contract was closed. On Monday they shipped two million pounds of copper into the Orford Works. On Tuesday the syndicate failed. Control of the works reverted to Thompson, also the copper to liquidate damages.

Thompson had by degrees paid off most of his debt to Clark. There remained, however, a final payment which curiously enough became due the very day he received his first payment from the French syndicate, in fact the money came to Thompson after banking hours on Saturday and it was only by special arrangement through his friends in the bank that he succeeded in making the final payment to Clark a few hours before it became due, thereby retrieving the Orford Works not only from the French syndicate but also from his financial backer who had a substantial lien on it.

IN our interest in technical matters, we are too prone to keep our noses to the scientific grindstone and neglect other interesting phases of metallurgy. The early struggles of metallurgical pioneers are worth recording. History of a sort can be written from documents, but the vital histories are those written by those who can say, "All of which I saw, part of which I was."

What interest we should have in the personal comments of men like Professor Henry M. Howe and Dr. Richard Moldenke on the metallurgical panorama unfolded in their lifetimes!

METALS & ALLOYS, especially through some of its Editorial Advisory Board, is interested in catching, before it is too late, some of the things those now living can record as to the historical development of American metallurgy.

Articles such as this will be published from time to time, and we urge our readers to pass on to us for publication any notes of historical interest relating to American metallurgy, even though they may be but fragmentary.

News of important discoveries of copper ore in Ontario reached Thompson in 1885 and he sent John Blue to Sudbury to investigate.

Canadian Copper Company

Sudbury was at that time the terminal point of the Canadian Pacific Railroad, from which construction was being pushed around the north shore of Lake Superior. The country was very rough and covered with "brulé," i. e., burnt and fallen timber. In 1884 the Canadian Pacific Railroad had driven a cut through an outcrop of good ore which afterward became the Murray Mine. News of the find spread rapidly and prospectors began to flock into the new mining country. Thomas Frood, Henry Ranger, Rinaldo McConnell, James Stobie, William McVittie, A. McCharles, Robert J. Tough and W. B. McAllister were some of the pioneers who staked out claims.

Samuel J. Ritchie, a Cleveland manufacturer, also heard of the discoveries of rich ore near Sudbury. In Ottawa that year he had seen a piece of copper ore taken from the Canadian Pacific Railroad cut and promptly went to Sudbury to investigate. Ritchie was a natural promoter, capable, energetic and persuasive. For some years he had been going to Canada for the second growth hickory he needed for carriage building in Ohio. As far back as 1882 he had found an 80,000 acre tract of iron ore in Hastings County, which he purchased; and with the assistance of Cleveland friends he had organized The Anglo American Iron Company. Senator H. B. Payne was an important factor in this enterprise and also assisted Ritchie in building the Central Ontario Railway from Trenton, Ontario, to the Coe Hill Mine. Some ore was sent for test from this mine to a blast furnace in Cleveland and unfortunately found to contain too large a quantity of sulphur to be used for making pig iron. Mining in Hastings County came to a sudden stop and the railway seemed doomed to become "two streaks of rust and a right of way." In 1885 the Hastings Iron Mines and the Central Ontario Railway were in a state of suspended animation, but not so Ritchie. His best chance seemed to be to extend his railway to join the Canadian Pacific and thereby secure part of the haul on ores which were coming in from Silver Mountain on the north shore of Lake Superior. When the Sudbury Copper ores were discovered, Ritchie visited all the properties and took options on several which appeared promising. Hurrying back to Cleveland he called together his associates of the ill-fated Hastings County venture and persuaded them that this was a chance to recoup their losses. On January 6, 1886, the Canadian Copper Company, with a capital of $2,000,000 was incorporated in Cleveland, Ohio, by S. J. Ritchie, Senator H. B. Payne, Henry P. McIntosh, Judge Stevenson Burke, Myron W. Keith and George G. Allen.

Discovery of Nickel in Sudbury Ore

The report which John Blue brought back from Canada resulted in a contract between Thompson and the newly formed Canadian Copper Company, in which they were to furnish him 100,000 tons of copper ore, guaranteed to contain not less than 7% copper. On May 1, 1886, mining was started at the Copper Cliff Mine and later in the year the Evans and Stobie Mines were opened up. L. H. Ashmun was the first superintendent and John D. Evans the first engineer and general manager. In October of that year the first ore was shipped to the Orford Copper Company. A small lot was also shipped to the Nichols Chemical Works at Laurel Hill on Long Island. The first shipments caused no little consternation. The metal extracted from the ore was not the customary copper but a pale white metal which could not be sold to the copper customers. The Laurel Hill people were not inclined to trouble themselves further with the ore and shipped what they had to Orford. Thompson, however, set about to make an investigation, ordering a complete analysis of the ore. The works chemist, Robert R. Hedley, reported 2½% nickel. Thompson wired Ritchie that the ore was not up to the 7% copper specified in the contract and Ritchie came post-haste to Bayonne, greatly disturbed by the report Thompson had made. When he finally understood that the nickel contained in the ore was the cause of the difficulty and also learned from Thompson that a dollar a pound was the current price for nickel, he became as highly elated as he had formerly been depressed and rushed off to Cleveland to tell his stockholders the news. He advised building a smelter at once near the mines in Canada and his recommendation was immediately approved. It was well enough to make copper-nickel matte from the ore, but, as Thompson explained to Ritchie at the time, none of them understood the metallurgy of a copper-nickel separation nor the refining of nickel after it was separated.

Markets for Nickel

Joseph Wharton, the pioneer in nickel in America, had a small refinery at Camden, New Jersey, producing since 1862 nickel from the ores of the Lancaster Gap Mine in Pennsylvania. In 1876 he exhibited some very remarkable specimens of rolled and wrought nickel at the Centennial Exposition at Philadelphia. In 1885 he was producing about 130 tons of nickel a year.

The French "Société Le Nickel," controlled by the Rothschilds, with a capital of $12,500,000, dominated the nickel market, owned the nickel mines in New Caledonia, an island in the South Pacific, and had been smelting and shipping ores since 1875. At this time (1886) they were producing from 500 to 800 tons of nickel a year. Other countries were small producers. Norway contributed about 75 tons and the German mine at Frankenstein was a small irregular producer. All told, the world's production of nickel in 1886 was about 1000 tons. From ore in hand the Canadian mines were ready to turn out double that amount. The price of nickel had declined steadily from $2.60 per pound in 1876. From 1879 to 1883 it had been in the neighborhood of $1.00, steadily falling off in 1886, plainly indicating an oversupplied market. German silver, nickel plating and coinage metal were practically the only uses for nickel. The properties

First house in Copper Cliff

James McArthur

of the metal were not generally known. The entire future of the Canadian Copper Company depended upon finding new uses for nickel.

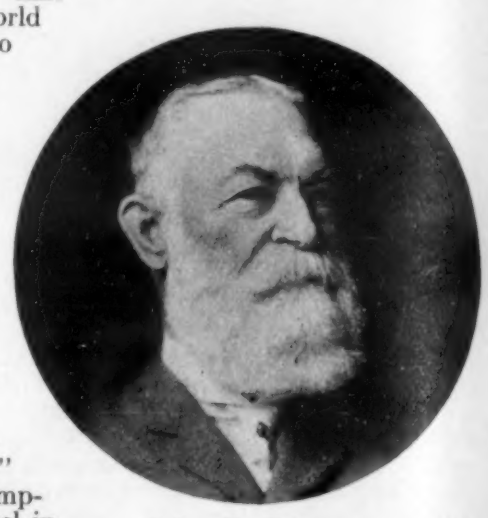
Ritchie recalled experiments made by John Gamgee, an Englishman whom he had met in Washington, D. C., some ten years before. Gamgee was greatly interested in the problem of yellow fever in the Southern States. It had only recently become known that the yellow fever germ could not live at the temperature of freezing water. Gamgee conceived the idea of building a refrigerated hospital ship to house yellow fever patients and freezing them back to health. He received an appropriation of $250,000 from Congress and the shops at the Navy Yard in Washington, D. C., were placed at his disposal for experiments in the construction of a refrigerating machine. His great trouble was to find a metal which was impervious to and unattacked by ammonia gas at high pressures. While walking together through the Smithsonian Institute, Gamgee and Ritchie noticed a large polished section of a meteorite. Inquiry brought out that this natural alloy of iron and nickel was exceedingly tough and strong. It occurred to Gamgee that such an alloy might fill his need. He sent to Joseph Wharton of Camden, New Jersey, the only manufacturer of nickel in America, for some nickel and made a number of iron-nickel alloys. One of these, containing 8% nickel, was exceptionally strong and seemed to be just the material desired for his compression cylinders. Ritchie followed these experiments and was greatly impressed with the properties of this ferro-nickel. Gamgee had some difficulties with his Congressional Committee. Cold weather put a stop to the epidemic that had engaged public attention. The hospital ship was never built. But this experience, showing the wonderful properties of iron-nickel alloys, made a lasting impression on Ritchie's mind. Recalling this incident ten years later, he wrote to Krupp at Essen, telling him of Gamgee's Washington experiments, suggesting these iron-nickel alloys for guns. Krupp treated the matter lightly, refusing to believe that there was a sufficient quantity of nickel in the world to warrant experiments involving an extended use of the metal.

Nickel Steel

However, the manufacture of nickel steel had been commercially undertaken in 1885, when ferro-nickel was manufactured at Marbeau's Works at Montataire, France. The French "Société Le Ferro-Nickel" had conducted numerous experiments with this combination in 1883–1884. These alloys were brought to the attention of the Iron and Steel Institute of Great Britain. James Riley, manager of Chas. Tennant & Sons Company of Glasgow, conducted, with great care and exactness, a series of experiments which were reported in a paper read before the Institute in May 1889. In the summer this report was brought to the attention of General Benjamin F. Tracy, U. S. Secretary of the Navy, who had also received from the American Naval Attaché in Paris a report that the great French steel works of Schneider & Company at Le Creusot had made some armor plate from nickel steel, which was very superior to the armor plate produced theretofore. Tracy immediately grasped the importance of this news and sent Lieutenant B. H. Buckingham of the U. S. Navy to France to investigate this new nickel steel alloy. Sir Charles Tupper, then Canadian High Commissioner in London, was also asked by Sir John A. Macdonald to investigate the question for the interests in Canada. Ritchie also went to France and on his return at once began to negotiate for a sale of nickel to the Navy Department. Upon Buckingham's return, Secretary Tracy ordered a nickel steel armor plate made at the famous Creusot Works, and also a plain steel plate, such as was then used by the British Navy, made at the works of Cammel and Company at Sheffield, England. These plates were brought to the Government proving grounds at Annapolis, Maryland, and tested at short range with eight-inch armor-piercing shells. The superiority of the French nickel steel plate was decisively demonstrated. Standard armor plate of carbon steel, as supplied to the British Navy, was shattered to pieces, while the nickel steel plate was not perforated nor did it develop a single crack. Reports of the results were heralded all over the world.

Thompson Makes His First Nickel

It was not long before Thompson heard through Captain Albert S. Barker that the Navy was actively in the market for nickel. Congress voted a large Naval appropriation for the purchase of 5,000,000 pounds of nickel to be used in making steel for the Navy. Commodore W. M. Folger, Chief of the Bureau of Ordnance in Washington, got to work with the steel people and with Secretary Tracy looked into the question of sources of supply of nickel and price. Thompson went to Washington and gave his opinion that for the quantity of nickel they required the prevailing price of $1.00 a pound was too high. Mr. Tracy pounded the table and told Thompson he was "a very ignorant young man;" that they had inquired the world over and were unable to get any nickel for less than a dollar. Thompson withdrew without comment and returned to New York. When he arrived at his office next morning, who should be waiting at his desk but General Tracy, who continued the conversation of yesterday by saying—"Mr. Thompson, you are a very sudden young man."



John D. Evans

As already stated, Thompson had discovered nickel in the Canadian ore some three years before, and Ritchie had persuaded his Cleveland stockholders to build a smelter at the mines in Canada. Thompson showed Tracy, from his letter copy book, the price he had paid the Canadian Copper Company for 1000 tons of matte on which he was experimenting, whereupon the Secretary asked him to arrange a purchase for the Navy Department on similar terms, or better, if possible. Thompson agreed, adding that he would not accept a commission for his services. Such was the first of many instances of Thompson's devotion to the Naval service which had given him his education and early training.

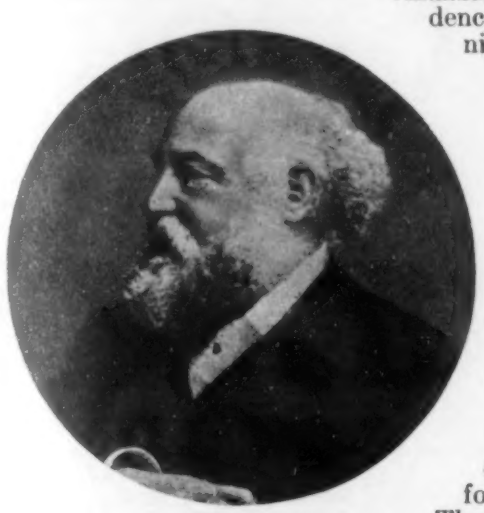
Henry Ranger (left) and A. McCharles, early prospectors in Sudbury area

Before long Senator H. B. Payne and Henry P. McIntosh had arranged with Secretary Tracy to furnish, on terms similar to those which Thompson had stated were possible, all the copper-nickel matte the Navy wanted. Although Thompson was experimenting on refining this matte he was not prepared to undertake any deliveries of nickel. He knew that there was only one competent nickel refiner in the country, Joseph Wharton.

One day, while in Washington, Thompson drew an informal memorandum of procedure by which the Navy would buy matte, deliver it to the refinery duty free, also with no charge for copper, receiving in return nickel at a cost of about 23 cents a pound. Thompson went back to New York, quite pleased with himself and feeling that he had set a

pretty fair price for Wharton. As he expressed it, the Navy could start with this low offer and let Wharton do the bargaining. The plan turned out to be somewhat of a boomerang for Thompson. The Navy decided they were in no hurry for the nickel. They knew Thompson was experimenting on nickel refining so they shipped the matte to him at Bayonne, New Jersey. When, at the end of a year, the time came to start delivery of nickel, Thompson was able to ship a red oxide of iron and nickel which was acceptable to the steel makers. There was only one difficulty, his costs were equal to or greater than the toll paid him by the Navy for extracting the nickel from the matte.

On a trip to Washington, when deliveries of nickel to the steel companies for the Navy were nearing completion, Commodore Folger handed Thompson a bill for about $180,000, covering duty on copper in matte delivered at Orford. This was an enormous and staggering bill, as on the entire work Thompson had cleared only about $25,000. There had been no formal contract but on the original memorandum Thompson had drawn for the Navy Department's guidance in dealing with Joseph Wharton it was stated that the copper was to be delivered no charge, also that the Navy would pay the duty. Thompson's exact recollection of this unsigned memorandum was all that saved him from financial ruin. The steel makers had taken about 5,000,000 pounds of nickel from Thompson, in the production of which he had gained valuable experience and confidence in his ability to get the nickel out in quantity.



Dr. Ludwig Mond

Orford Process

In 1890 little was known by American producers on the metallurgy of nickel. Joseph Wharton and Thompson were the only producers. Expensive wet processes were the rule. Vivian, at Swansea, Wales, was also extracting nickel from copper-nickel ores but information was hard to get. Thompson's method of treatment gave him undissolved residues which were returned to the furnace for a second smelting, followed by further grinding and leaching. Each time some nickel was extracted but a good part was held in the residues.

Cone-shaped pots were used to take the matte away from the cupola and dumped on the floor when cold. While visiting the works one day, Thompson tapped one of these cones with a sledge hammer and observed an unusual fracture. Of about 100 pots of matte on the furnace floor that day, 18 or 20 broke in the same way. The bottom third showed bright sulphide, the top dark and flakey. Samples were taken, and to Thompson's surprise showed the bottom to be almost pure nickel sulphide and the top copper, nickel and iron. The works superintendent was not impressed by the incident but on inquiring among the men Thompson learned that a lot of residues from the chemical house had been thrown into the furnace at the time this unusual matte was made. Tradition has it that Wm. Gibb, head sampler, a careful Scotsman, told Thompson what had happened. It was clear to Thompson that some chemical change of importance had occurred. Complete analysis made of the "top" showed a notable amount of sodium. Thompson put one of his foremen, Charlie Bartlett, to work melting matte in crucibles with all the different chemicals in the works. Nothing unusual was noted until the very last crucible heat which gave a product similar to the "top" and "bottom" from the cupola. In this last heat the chemical used was nitre cake, a by-product of nitric acid manufacture. Thompson bought a carload of nitre cake, tried it in his cupola and got the expected result.

W. E. C. Eustis

Realizing that he had run across something unusual, which might have an important bearing on his nickel experiments, Thompson set to work on the theory of his discovery and applied immediately for patents. In the course of securing them an interesting previous experiment of like nature was turned up. In 1877, Wm. B. Tatro, a shoemaker of Hartford, Conn., had experimented on similar copper-nickel ore from a nearby deposit. The kitchen stove was his furnace. He secured a patent on separation of nickel from copper and iron by melting the sulphide ore with a mixture of lime, fluorspar, saltpeter and potash. Thompson went to Hartford to look up Tatro and found that he had been dead some years and that his patent had been assigned to a small company of which only a few stockholders were still living. Administration papers were applied for, the company brought to life and Tatro's patent purchased.

Thompson went ahead with his new practice for separating copper and nickel by the tops and bottoms method, which became known as the "Orford Process," and soon had a quantity of nickel sulphide from which he produced metallic nickel of fair quality. He took it to the steel people, who had been using his red nickel-iron oxide. At first they did not want to give up the use of oxide but soon found the nickel pig satisfactory. Thompson shipped what oxide he had on hand and thereafter shipped metallic nickel.

About 1890 the management of the Canadian Copper Company passed from Ritchie into the hands of Henry P. McIntosh, who made a contract with Thompson to refine the entire output of copper-nickel matte for a period of five years and sell both the nickel and copper. The matte was to contain about 20% nickel and 15% copper. Thompson agreed to advance the cash to pay the cost of producing the matte and to pay the freight to Bayonne, New Jersey. When the nickel was sold he was to deduct the amount advanced and his toll charge for treatment, the balance to be divided equally between the Canadian Copper Company and Thompson. If the nickel could not be sold Thompson was to store it and borrow money on it to pay his advances and toll. The matte from Canada began to come in very fast. Sales of nickel were slow and money hard to get. The pressing question for the Canadian Copper Company was a market for their copper-nickel matte, which depended upon Thompson's ability to sell the nickel.

Senator Wm. A. Clark, pioneer in the copper industry

Financing the Canadian Copper Company

As reports of the rich ore supplies of Ontario spread abroad, European producers of nickel soon made inquiry as to the control of this new source of supply. Both the Rothschilds and Krupp representatives wanted to buy control of the Sudbury Company. Prior to the arrangement with Thompson they offered contracts for a ten year period, agreeing to take a large amount of nickel each year. The finances of the Canadian Copper Company were at this date (1889–1890) none too good. The temptation was great to transfer the mines and smelter to the control of foreign firms at a large profit. There had been little sale for the matte. There was no quick method for separating nickel from copper. Matte was piling up in the smelter yard and was not a commercial asset. The banks would not lend money on it. To keep the work going, three men, Judge Stevenson Burke, Senator Henry B. Payne and Thomas Cornell, pledged their individual fortunes, accepting overdrafts of $200,000 to $300,000, secured by their personal

endorsement. The faith of these men in the future value of their property, together with the assistance of Sir Charles Tupper and Sir John A. Macdonald, prevented the transfer of the Canadian Nickel industry to the French Société Le Nickel or to the firm of Krupp at Essen. Resisting the solicitation of the Rothschilds and Krupp, three American citizens, in the presence of the representative of the Dominion of Canada, pledged their faith in the future of their enterprise. Even after securing the contract with Thompson progress was slow, as the sales of nickel were small and for eight years these men carried the burden of the credit of their company. The history of industry affords no finer example of optimism, loyalty and determination to win.

The growth of the nickel industry was very slow and competition was keen. Vivian of Wales, in 1889, purchased the Murray Mine and started a smelter. In the same year the Dominion Mineral Company started work on the Blezard Mine and produced some matte. The Drury Nickel Company was organized in 1891. Here were four companies, all competing for a limited market, which soon became overstocked and collapsed. The French nickel company met every offer of Canadian nickel with lower prices.

Soon after Thompson commenced deliveries to the steel people on his contract with the Navy Department, he went to England where he made the acquaintance of all the large consumers. He was fortunate enough to get on good terms with Henry Wiggin and Sons at Birmingham and through them opened a market for his nickel. The first year he wanted to dispose of 500,000 pounds of nickel, then selling at 60 cents a pound. He went to the Société Le Nickel and offered them metal at 50 cents a pound and promised not to invade their market if they would purchase from him. They declined his offer and he sold his nickel in Germany. Next year he went again, this time to dispose of 1,000,000 pounds. Their price was now 50 cents. He offered the nickel to Le Nickel at 37 cents and was again courteously refused. This time he sold to Bernsdorf in Austria. Before the end of the year nickel was selling at 25 cents a pound. While in France, Thompson made the acquaintance of Baron Adolphe de Rothschild and succeeded in winning the lasting friendship of this his most powerful competitor.

H. P. McIntosh

With such a highly competitive state of affairs nobody was making any money and the weaker companies went to the wall. Vivian withdrew from the struggle in 1894. The Drury Nickel Company went under in 1893 and the Dominion Mineral Company in 1894. It was a war for recognition of Canadian nickel. None of these could stand the strain of foreign competition. The Canadian company was saved a similar fate only by the courage of its directors and Thompson's success with Baron Rothschild.

Ambrose Monell, former Vice-Pres. Int'l Nickel Co.

Development of Canadian Plant

Let us turn for a minute and look at the conditions at Sudbury when work was started in 1886. Only the steadfast determination of the men on the ground, with primitive surroundings and meager resources, brought the mines and smelter through to a satisfactory production position in a relatively short time.

The Algoma branch of the Canadian Pacific Railway, built at the time of construction for transporting supplies and building material to the main line, had been abandoned. Sudbury was situated on this branch line. Cars could be moved over it at a maximum speed of 8 miles per hour. There was no side track from the railroad to the mines. Freight from the outside to this north country was incredibly slow. Sir William C. Van Horne, President of the Canadian Pacific Railway, was a staunch friend of the struggling mining company. His railroad was new and traversing a difficult and undeveloped country. Every facility the railroad had was freely and cheerfully given to assist in opening the mines.

Dr. E. D. Peters

William McVittie

In May 1888 Dr. Peters was engaged by the Canadian Copper Company and went to Copper Cliff to pick out a site for a roast yard and smelter. The roast yard was staked out on a clay flat, beside a little stream which beavers had dammed. The beavers objected to the destruction of their water works and repaired the dam at night as fast as it was torn away. By August, however, the roasting of ore started. A furnace building of frame, 40 feet long and 35 feet wide, was erected, boilers and blowing engine installed. This work went very slowly. There is a letter from Peters, written in November, in which he speaks of having to send all the way to North Bay, 80 miles, to get the pipe he needed, cut and threaded.

During this month H. P. McIntosh, the secretary-treasurer of the Canadian Copper Company, wrote to Peters asking if it would be possible to enlarge the plant sufficiently to smelt 300 tons of ore a day. Peters replied that he thought he could do it but such large figures were rather bewildering. Even 100 tons of ore a day was enormous and almost unprecedented.* In the fall a Herreshoff water jacket furnace, 6 feet long, 3 feet wide and 9 feet high, built by the Nichols Chemical Company and shipped in sections, was erected. The method of assembling showed more ingenuity than knowledge of furnace practice, as will appear.

On December 22nd the furnace was blown in, with a crew of French Canadians who had never seen a furnace. The water jacket immediately developed a leak which seemed impossible to find. Soon the floor of the furnace room was flooded and every time the furnace was tapped explosions sounded like a Gatling gun. James McArthur, who was in charge of the work and an experienced smelter man, had to do most of the work himself. An improvised platform was built above the settler and on it two men were stationed with pails to put out fires on the roof that followed each tap. Christmas Day they had to stop work through sheer exhaustion. McArthur's eyes had been badly burned, in fact so much so that a boy was told off to lead him around the smelter building. The trouble was easily located when the furnace was shut down. A bronze connection ring between the furnace and settler, designed hollow and water cooled, had been sawed in four pieces and set loosely together inside the iron work. With matte and slag running continuously through this split ring the furnace was kept going for three days and shut down without serious damage. After considerable vituperative correspondence with the assembly shop, a new tapping ring was fitted, this time in one piece.

In January (1889) the furnace was started again and Dr. Peters was delighted to find that he could smelt from 80 to 100 tons of ore a day, producing a 35% matte and slag with 1½ to 2% copper-nickel. This matte was shipped to H. H. Vivian, Swansea, Wales; to Chas. Tennant in Glasgow; to Thompson at Bayonne; to Joseph Wharton in Camden, and to Hamburg. In 1889, 8450 tons of matte were produced, containing 22% copper and 14%

* Current practice at Copper Cliff is 6000 tons of ore a day

Sir John A. Macdonald

nickel, or about 1000 tons of nickel. This was twice as much nickel as the entire world produced in 1888. From this time on the Canadian Copper Company produced copper-nickel matte steadily and, as stated above, sold the entire output to Thompson at Orford for a period of 5 years.

Mining and smelting at Copper Cliff were developed in the face of numerous difficulties. The Copper Cliff, Evans and Stobie Mines supplied all the ore from 1888 till 1898, when No. 1 and No. 2 Mines were opened. At that time these were called the McArthur and the Great Jones Mines. Jones was a mine captain in the early days, who became too corpulent to get down the ladderways and used to stand for hours at the top of the shaft directing the work. Hence "Great Jones."

The ore was all roasted by contract, first at 20 cents a ton and in 1893 at 17 cents a ton. The contractor, Dan McKinnon, produced good roast ore containing not over 7% sulphur. The piles burned for about 100 days.

Samuel J. Ritchie

The smelter at Copper Cliff grew as need demanded, furnaces being built as convenience permitted. They were all Herreshoff furnaces, fed by what was called the "patent English wheel barrow system." There were no labor-saving devices. By hard work and perseverance James McArthur succeeded in getting two furnaces going by 1890, each smelting about 125 tons of ore a day. When you consider the short period since the opening of the mining district, McArthur's achievement was a splendid piece of work.

Although mining and matte making were now fairly well established, much was to be desired in economies and as yet there was no established market for such a large production of nickel. No one in America, excepting Thompson, was marketing large quantities of nickel, nor was there any one, excepting Joseph Wharton, who could speak with authority on the properties and uses of the metal.

Jules Garnier Comes to America

M. Garnier, who in 1867 discovered the New Caledonia Nickel mines, came to Sudbury in 1890, engaged by the Canadian Copper Company to assist in solving their problems. He was a courteous French gentleman, with the Legion of Honor ribbon in his immaculate frock coat. With him came M. Michaud as assistant.

The first problem that engaged M. Garnier's attention was the erection of converters to make a higher grade of matte. The matte then produced contained 35% copper-nickel and it was thought possible to increase this to 80%. The building of a Bessemer plant at Copper Cliff went on in the winter of 1891–1892. At the last moment, when everything was ready, a large butterfly valve for the blast pipe was missing. Frantic telegrams to the maker traced this up from the time it left the foundry till it arrived at Copper Cliff. The warehouse at Copper Cliff was certain that it had been sent to the Bessemer shop and the Bessemer shop was equally certain that it had never been received. A heaven-sent office boy finally remembered riding down to the smelter on the sleigh with the box in question, so McArthur armed a number of men with poles and set them prodding in the deep snow around the smelter. After a long search the missing valve was found.

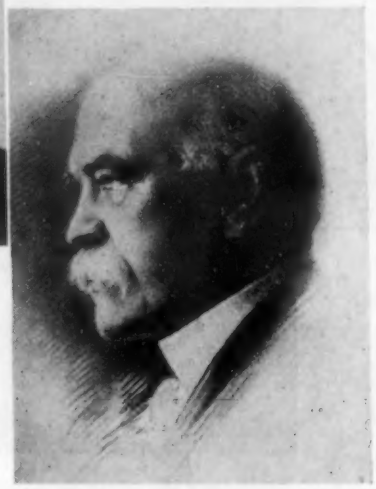
The Bessemer plant was started January 23, 1892, and made matte of the desired content. In spite of many crudities the first Bessemer plant was undoubtedly a great success and a distinct advance in the smelter practice of the day.

Refining Experiments at Cleveland

With an 80% Bessemer matte the possibility of carrying the refining to a finished metal was worth considering. All realized that if a market could be found for such a copper-nickel metal it would be a tremendous help, for as it was, the market for copper-nickel matte depended entirely upon existing markets for nickel. M. Garnier succeeded in making a very good copper-nickel alloy containing 50% of each metal and secured a small market for it in France. This was the first alloy of the Monel Metal type made from Canadian ores.

Another problem undertaken by Garnier was the production of pure nickel from oxide. Under contract with Thompson the Canadian Copper Company could, if they desired, take the Orford Nickel oxide and reduce it themselves. With this plan in view a plant was erected at Cleveland, under the supervision of Garnier and Michaud. The oxide was mixed with clay, charcoal, lime, fluorspar, ground in a pug mill, pressed into bricks and dried in an oven. The bricks were then melted in a cupola furnace with hot blast. Even the resourcefulness of Garnier was taxed to the utmost in these attempts to refine metallic nickel from oxide. Some nickel shot was produced but the results in the main were not satisfactory. Carl Hoepfner came from Germany to Cleveland in 1893 to assist in the experiments. He had a method for producing nickel by dissolving the matte and plating from the solution first copper and then nickel. The copper was plated successfully but all attempts to secure a satisfactory nickel failed, and Hoepfner's method was abandoned. D. H. Browne, chief metallurgist of the Canadian Copper Company, some years later developed a successful electrolytic process for the production of nickel.

Col. R. M. Thompson



Mond Process

By 1896 the Mond process was beginning to attract attention and although a sensitive temperature control was necessary it was suggested that the process could be used in the cold climate of Canada. In the fall of that year D. H. Browne and W. A. Hooker visited England to make an investigation of Mond's process and on their recommendation the Canadian Copper Company took an option to purchase the patents and process for $1,500,000. In 1897 Browne and Hooker took 75 tons of Canadian Bessemer matte to England and spent a year studying the Mond method.

The discovery by Dr. Ludwig Mond of a method of separating nickel and copper was quite as accidental as the discovery of the Orford process. Dr. Mond and Dr. Langer were attempting to obviate breakdowns in certain valves used in a plant for producing chlorine. Nickel had been chosen as the metal for these valves in the belief that it would resist the corrosive effects of vapors passing through them. The valves not only proved leaky but became coated with carbon. These observations led to a careful study of the chemical reactions of carbon, oxygen and nickel.

The Mond process consists in treating a finely divided metallic nickel with carbon monoxide gas which picks up the nickel, forming nickel carbonyl gas. On passing this nickel carbonyl gas over heated nickel grain the gas is decomposed and each grain receives

Prof. H. M. Howe, Mgr. & Consulting Engineer Orford Copper Co.

an outside coating of nickel. This process is one of the most beautiful known to metallurgy. The simplicity of the operation constitutes its chief charm. At that time, however, the mechanical difficulties in handling it had not been solved. After careful investigation Browne came home and the Canadian Copper Company decided not to take up its option on the Mond process.

Companies Other than the Canadian Copper Company Operating Canadian Ores

Not long after the Canadian Copper Company relinquished its option, the Mond Nickel Company was formed and about 1900 commenced mining ore in Canada. In 1901 and 1902 the Victoria and North Star Mines were opened and a smelter erected. Hiram W. Hixon was the first general manager. The smelter was scientifically planned and economically administered. The product was an 80% Bessemer matte which was shipped to Clydach, in South Wales, for refining.

There were also the following activities which were, however, short-lived. The Vivians who, as already stated, closed down the Murray Mine in 1894, kept their smelter at work from August 1896 to January 1897 on roasted ore, which was sold to Joseph Wharton. The Drury Nickel Company, after closing down in 1893, was reorganized under the name of the Trill Nickel Mining & Manufacturing Company and did some smelting at Sudbury about this time. Their product was also shipped to Wharton's refinery at Camden, N. J. A year or two later the Great Lakes Copper Company, after purchasing the Mount Nickel Mine, built a smelter on designs furnished by an Austrian metallurgist, Anton Graf, which also proved unsuccessful. In 1899 Hoepfner came back to Canada to make a second trial of his ideas on nickel refining, this time for a Company organized by a group of Hamilton men. After sinking a great deal of money in a smelting works erected at Hamilton, Ontario, the Hoepfner method was abandoned. Hans A. Frasch had been resident manager at Hamilton under Hoepfner who died suddenly in Colorado about this time. Frasch attempted to carry on the work for a time but was unsuccessful and the whole enterprise abandoned. Closely associated with this attempt was the Nickel Copper Company of Ontario, Ltd., which bought the Whistle Mine and operated it until the collapse of the refining company.

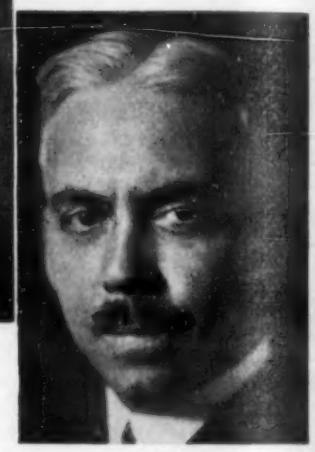
Although much effort and money had been spent in a variety of attempts to refine nickel in Canada, all successful activity had been confined to the production of Bessemer matte. Refining had just been started by the Mond interests in Wales when a bill was passed by the Canadian Parliament, empowering the Governor-General to apply such restrictions on the export of nickel in matte from Canada as he deemed necessary, to bring the refining of nickel to Canada. Stimulated by the prospect of advantages of refining in Canada, the Lake Superior Power Company, with F. H. Clergue as president, entered the nickel field. The Gertrude and Elsie Mines were purchased and a railroad built from the mines to Sudbury. A smelter was erected in 1902 and copper-nickel matte shipped to Sault Ste. Marie, where an attempt was made to make an alloy pig iron. Experiments were continued until 1903 when a demand by the bond holders brought the Ontario Government to the rescue. The iron and steel business, made from ores in the "Soo" district, kept the company going for several years after the attempts on Sudbury ore had been abandoned. The common difficulty with most of the attempts on Sudbury ore was that the finished product was matte for which there was a very limited market. The mining of ore and smelting of matte, as stated before, were comparatively simple. What to do with the matte, how to separate the metals and where to find a market for the nickel, were the rocks on which all of these companies broke.

David H. Browne

W. A. Bostwick

Robert C. Stanley

Jas. L. Ashley



T. B. Wickenden

Orford Works Becomes Important Nickel Refinery

For some time R. M. Thompson had been sole owner of the Orford Copper Company. Refining problems at Orford were still unsolved and there was no one available who had had much experience in refining nickel metal. Ores similar to the Canadian copper-nickel sulphides had been worked in Sweden for some years. N. V. Hybinette, a Swedish metallurgist highly experienced in refining nickel, had some few years before built a nickel refinery in Norway. Upon the appearance of cheaper nickel from Canadian ores it was necessary to close down the Norway refinery and Hybinette came to New York seeking his fortune. He offered his services to Colonel Thompson and was engaged in 1892. When John L. Thomson, superintendent at Orford Works, retired in 1897, R. R. Maffett, a nephew-in-law of Colonel Thompson, was appointed superintendent of copper refining and Hybinette was appointed superintendent of nickel refining. Measured by the standards of to-day much could have been asked, but compared with other existing methods the practice was far in advance of any. Before long Hybinette was making a high quality nickel oxide and pig. He also did the first electrolytic refining at Orford Works, which laid the foundation for the high quality electrolytic nickel produced to-day, 99.9% nickel. With many years' experience Hybinette is to-day one of the leading authorities on the metallurgy of nickel.

The old Bessemer plant, erected by Garnier for the Canadian Copper Company at Copper Cliff in 1891, had long since fallen into disuse. Small lots of this 80% matte had been made from time to time for the company's refining experiments in Cleveland. Thompson, however, had been unable to persuade the Canadian Copper Company to give him a concentrated matte and in 1900 was still getting a 35% matte, which involved paying freight on a large tonnage of waste material, whereas if he could get an 80% matte it would be more economical all around. As the Canadian Copper Company could not be persuaded to give him a high grade matte, Thompson in 1900 built some furnaces himself at Copper Cliff to produce it. In 1901 Hybinette built the Ontario Smelting Works, opposite the Canadian Copper Company's smelter, where he ground and roasted the low grade matte, re-smelting it to a concentration of 65% copper-nickel. This higher quality matte greatly improved Thompson's practice and productive capacity at Orford.

About this time the same threat of a prohibitive duty on the export of nickel from Canada, which prompted Clergue to enter the nickel field, forced Colonel Thompson to discontinue the use of Canadian nickel at Constable Hook, N. J. For over a year he got his nickel requirements from the mines of New Caledonia.

Although Orford had by this time become the largest nickel refinery on the continent, nickel did not displace copper as its principal business un il some years after the consolidation of the Orford and Canadian Copper Companies in 1902.

The Orford Copper Company had become one of the largest custom copper refineries on the Atlantic Seaboard. Ores came in from the growing western copper mines, from South America;

crude copper from Japan and other far eastern points, also large quantities of copper scrap for refining. The output of copper was from five to eight times as great as the output of nickel.

The refinery had grown up as need demanded. As far as nickel was concerned, Thompson's ore supply was in the hands of others. For this reason no large capital expenditures were being currently made for permanent betterments.

The Canadian Copper Company in 1900

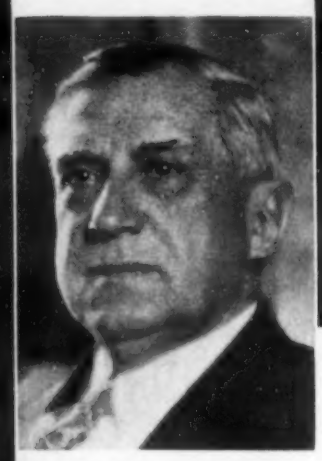
The conditions of the nickel business at the opening of the twentieth century were not too happy for any of the parties concerned. The Canadian Copper Company found the market opportunity much less plentiful than its supply of copper-nickel matte. The mines were in good shape, furnaces were producing good matte, but for disposal of their matte they were dependent upon Thompson's sales of nickel.

In October 1899, A. P. Turner of the Cleveland office was sent to Copper Cliff to be McIntosh's representative on the ground. McArthur became manager of mines and smelter and shortly afterward John Lawson, a mining man with experience in the Michigan iron mines, took charge of ore development. McIntosh, as manager and director of the company, had for some time been making every effort to develop the refining of nickel and in this way not be wholly dependent upon sales of matte to Orford for the prosperity of his company.

F. B. Coyle

J. L. Agnew

Dr. P. B. Merica



Charles M. Schwab

E. F. Wood

The success of Browne's electrolytic process at Cleveland was an important achievement for the Canadian Copper Company as opening an outlet for finished products for the first time and was, in a sense, a declaration of independence from the Orford Copper Company. Copper refined from the matte was sold to C. W. Bingham of Cleveland and nickel was sold directly to manufacturers of German-silver in Connecticut. Although no large electrolytic refinery was ever built by the Canadian Copper Company, Browne's success established the possibility of their independence and was, therefore, an important factor in their discussions with the Orford Copper Company.

Canadian Copper Company and Orford Copper Company Join Forces

It had for some years been recognized that neither the Canadian Copper Company nor the Orford Copper Company could build for the future without the other. Large sums of money were needed to equip the plants of both companies with modern appliances and to develop the market for nickel. The subject of consolidation was discussed and, with the assistance of large steel interest and of the only other large nickel producer, Joseph Wharton of Philadelphia, carried into effect. In April 1902, the International Nickel Company of New Jersey was organized. This took in, in addition to the Canadian Copper Company, the Orford Copper Company and Wharton's American Nickel Works; the Anglo-American Iron Co. (the survivor of Ritchie's Hastings County Iron Co. which also owned some nickel lands in the Sudbury district), the Nickel Corporation of London and Société Minière Calédonienne, in which Colonel Thompson had acquired an interest when purchasing New Caledonian ore. The men who launched the new company were R. M. Thompson, Joseph Wharton, C. M. Schwab, E. C. Converse, E. F. Wood and Ambrose Monell. The last named became president, with E. F. Wood, vice-president, and J. L. Ashley, treasurer. Colonel Thompson, the nestor of the nickel industry, became chairman of the board.

The Canadian Copper Company was continued as a subsidiary company with A. P. Turner as president and F. S. Jordan as vice-president. In 1913 Turner resigned and soon after A. D. Miles was elected in his place. A few years later the Canadian Copper Company passed out of existence, all the Canadian activities and properties having been brought under one head as The International Nickel Company of Canada, Limited, which was organized in 1916.

Some years prior to the organization of the International Nickel Company of New Jersey, Thompson made a trip on snow shoes through the Canadian country to the falls of the Spanish River about 35 miles from Copper Cliff, at which time he bought the falls and a tract of land on each side of the river, also securing from the Canadian Government a guarantee of the right to the power of the falls. Soon after the organization of the new company he sold them this water power for $100,000, a very low figure considering the potential value to the company. Thompson's judgment at the time was that the company, and of course his interest in it, would be greatly enhanced by the introduction of cheap hydro-electric power. This valuable acquisition rounded out the company's physical assets. Development of the power commenced at once.

The dilapidated wooden buildings and obsolete machinery in use at Copper Cliff were replaced by what was then one of the most up-to-date smelters in the world. Smelting practice improved very rapidly after the building of the new smelter, and many economies were introduced at Copper Cliff. The original Anaconda type acid converters were discontinued for Pierce-Smith basic converters. Sintering slag and flue dust in reverberatory furnaces, with powdered coal as fuel, and later by Dwight-Lloyd sintering machines, was introduced to keep the losses in slag at a minimum. Electricity was introduced underground. The entire output of the Canadian smelter went to Orford for refining.

In 1904 Hybinette severed his connection with the company and R. R. Maffett became general superintendent of the Orford Works.

Dr. Wharton's American Nickel Works in Camden produced grain nickel during the first few years, made after the European practice from a medium quality nickel oxide, and also became a by-product plant of the company. Other products of the Wharton Works were nickel salts, cobalt salts, copper salts and small quantities of platinum metals, by-products from the Canadian matte. A by-product cobalt material, extracted from the matte at Orford Works, was refined at Camden and became the principal source of supply of cobalt oxide, until the discovery of the cobalt mines in Canada.

After taking his degree from the Columbia School of Mines and having spent some months investigating placer platinum sands in Dakota, R. C. Stanley,* in the spring of 1903, became Superintendent of Wharton's Nickel Works in Camden, N. J., with the writer as his assistant. In the fall Stanley was advanced to assistant general superintendent at the Orford Works and was succeeded at Camden by the writer. With the advent of the Canadian cobalt ores the production of oxide was increased to a tonnage equivalent to the world's requirements. The ores contained substantial quantities of silver. A very complex

* Now President of The International Nickel Company of Canada, Ltd.

metallurgical problem, involving the recovery of nickel, copper, cobalt, silver and arsenic, was successfully worked out, resulting in the erection of an arsenic refinery at the location of the old Ontario Smelting Works at Copper Cliff. Recovery of arsenic from these ores was an entirely new feature in the work of the company. After careful investigation by Stanley and under his direction, the plant was built and operated successfully for a number of years as an important producer of arsenious oxide. Treatment of these cobalt silver ores continued until 1912, at which time purchase of ores was discontinued, terminating the production of cobalt oxide and fine silver at Camden. Soon after this all the remaining operations at Camden were transferred to the Orford Works and the plant sold.

On the death of R. R. Maffett, in 1912, Stanley became general superintendent and the writer was transferred to Orford as assistant general superintendent.

Following Stanley's coming to the Orford Works in 1904, great advances were made in improving the metallurgy and practice of refining both nickel and copper. An important advance was made in the refining of copper by the installation of Bessemer converters in substitution for the more expensive and slow reverberatory furnaces. Outstanding improvements were also made in the refining of nickel. Mechanical furnaces were introduced to replace the old hand furnaces and the electrolytic refining of nickel was established on a commercial basis.

Monel Metal and Huntington Plant

Following the early experiments of Garnier, which resulted in a 50–50 copper-nickel alloy, and subsequent work by Browne, Stanley ordered in 1904 some special matte from Canada, low in iron, from which was made the first heat of what later became known as Monel Metal, an alloy of 70% nickel and 30% copper, which has since become well and favorably known throughout the world. From 1905 to 1922, ingots were made at the Orford Works, the rolling being accomplished at custom steel mills. The post-war market development demanded better and larger facilities for the production of Monel Metal and a rolling mill was built at Huntington, West Virginia, in 1921. The plant is both a refinery and rolling mill. The products are both nickel and Monel Metal, in a great variety of types and shapes. Since the opening of this plant the demand for Monel Metal has increased from about 3000 tons in 1922 to about 10,000 tons in 1929. The products of this mill have a wide and diversified field of usefulness where appearance and corrosion-resistance are important.

Effect of the World War on the Nickel Industry

By the fall of 1914 facilities for the production of nickel in all parts of the world were being pushed for a maximum output. During the early years of the war a large part of the production of the Norwegian nickel mines, refined at Kristianssands, found its way to Germany. Aside from a small production of nickel in Germany, this was the only supply available to the German war machine. A plan was formulated in England whereby, with the aid of Government funds, control of this Norwegian enterprise could be had and increased Empire production made available. The plan included a merger with the Murray Mine in Ontario and resulted in the organization of the British-American Nickel Company, with smelter and refinery in Canada.

Steady and increasing demand by the Allies for nickel during the war taxed all the resources of The International Nickel Company, from mines to finished products, to their utmost. The maximum refining capacity at Orford was insufficient and early in the war it was evident that additional refining facilities would be needed. In 1916 work started on a new refinery at Port Colborne, Ontario, with greatly enlarged electrolytic refining facilities. The building was pushed ahead steadily but, due to the many handicaps experienced in war time construction, was only completed a month before the Armistice, November 11, 1918. The new refinery embodied the experience of all the preceding years of work on nickel. It had all the improvements in process and equipment, as well as the advantage of ample space and suitable surroundings in which to place a modern plant.

Soon after the entry of the United States into the World War, Ambrose Monell was commissioned Colonel in the United States Army (Aviation) for overseas service. On September 15, 1917, W. A. Bostwick succeeded him as president of The International Nickel Company of New Jersey. Stanley was elected vice-president, in charge of all operations from mines to finished products. The writer became general superintendent of the Orford Works and H. W. Walter, assistant general superintendent.

At the close of the war the manufacture of war materials almost ceased, causing a shrinkage in demand for nickel to near the vanishing point. In 1920 the total world production of nickel fell back to that of 1900. The Orford Works at Constable Hook, N. J., being an old and high-cost producer, was shut down and dismantled during this industrial depression.

The newly formed British-American Nickel Company did not come into substantial production until after the war, when there was no market for nickel. This, together with high production costs, brought the company to a state of bankruptcy.

In 1922 Bostwick died and Stanley was elected president of The International Nickel Company of New Jersey. J. L. Ashley, who had been treasurer of the company from the time of its organization, was elected vice-president. John L. Agnew, who had been general manager of all the mining and smelting operations in Canada, was elected president of the subsidiary Canadian company.

The Armistice had brought to a close the era in which the company's prosperity was derived from the building of great navies and equipping the great armies, which up to that time had consumed the greater part of the world's supply of nickel. The facilities of the company for mining, smelting and refining nickel were intact, fully developed for a large production program. Stanley was confronted by the same condition which McIntosh met when he opened the first mine in Canada and Thompson told him there was nickel in his ore. It was necessary to find markets for the nickel.

Anticipating such a condition the writer had, during the last year of the war, organized at Bayonne a Research Department and Dr. J. F. Thompson had organized a Development Department. In 1922 these two efforts were merged and under the direction of the writer a systematic effort commenced on a study of the uses of nickel and methods of establishing and expanding them. The personnel for this work was chosen with great care. Much of its success is due to the fact that men of experience and standing in engineering fields joined the ranks of the company. Dr. P. D. Merica of the United States Bureau of Standards, who had joined the company in 1919 as director of research, built, equipped and manned a laboratory for the study of nickel and its alloys. New products of nickel, new alloys in both the ferrous and non-ferrous fields, resulted from this work. Special knowledge of the function of nickel in these alloys and of their suitability in many manufacturing fields, was made available to the engineering profession.

During the years from 1922 to date, steady progress has been made in developing markets for nickel. Information on nickel has been consolidated and brought within the reach of all possible users in industrial fields. In 1927 this work was extended to include both England and Continental Europe. Active centers have been established in London, Paris, Frankfurt, Brussels and Milan.

To meet the steadily increasing demand for nickel, The International Nickel Company of New Jersey considered it advisable to decide which of the company's valuable mining properties in the Sudbury district should be developed to supplement and eventually succeed the historic Creighton Mine. Of the many important mines owned by the company the Frood was selected, drilled and work commenced upon it in 1924.

More power was needed. A second and larger dam was built on the Spanish River, forming a lake 25 miles long, assuring full flow of water throughout the entire year. By placing the new hydro-electric power plant in tandem with the existing one, the water is used twice, thereby securing the maximum power output from a given flow of water.

The International Nickel Company of Canada, Limited, Acquires The Mond Nickel Company, Limited

In January 1929, through a consolidation, all of the property of The Mond Nickel Company, Limited, was acquired by The International Nickel Company of Canada, Limited, with R. C. Stanley as president. John L. Agnew was elected vice-president, James L. Ashley, secretary and treasurer, Dr. J. F. Thompson, assistant to the president, and Dr. P. D. Merica, technical assistant to the president.

The Mond Nickel Company, Limited, of England, had mines in the Sudbury district, including a part of the Frood Mines; a smelter at Coniston, eight miles East of Sudbury and a refinery at Clydach, near Swansea, South Wales, also rolling mills at Henry Wiggin & Company, Limited, in Birmingham, England, and a precious metals refinery in Acton, near London. The International Nickel Company of Canada had mines in the Sudbury area, including the larger part of the Frood mine, a large smelter at Copper Cliff, large hydro-electric power plants, a refinery at Port Colborne, Ontario, and rolling mills at Hungtington, West Virginia. This logical and economic fusion of interests obviates to a great extent the duplication of heavy capital expenditures in mining, smelting and refining operations.

Immediately upon the consolidation of these two large nickel companies, the independent plans of each company at the Frood Mine were merged into one comprehensive program. Work on a new and greatly enlarged smelter at Copper Cliff received new impetus, and it was completed in August 1930. At the same location the Ontario Refining Company, Limited, has erected and is now operating an electrolytic copper refinery under the joint participation of The International Nickel Company of Canada, Limited, Consolidated Mining & Smelting Co. of Canada, Limited, and The American Metal Company of Canada,

Limited, to provide sufficient capacity for a large increase in the production of copper which will be produced from the Frood Mine.

The refining facilities at Port Colborne, Ontario, and Clydach, South Wales, are both being greatly increased to meet future demand for nickel. Each of these refineries produces a very high purity nickel, which has almost entirely displaced shot and pig formerly produced from oxide. Both the carbonyl process of the Mond Company and the electrolytic method of The International Nickel Company also yield a complete recovery of precious metals of the platinum group. The precious metals residues from all plants are now refined at Acton, England.

The search for markets for nickel has been enlarged by the consolidation of these two nickel companies. The principal business of the Mond Company having been abroad, their research laboratories and personnel considerably augment the work of the foreign bureaus of The International Nickel Company.

On July 9, 1931, John L. Agnew, vice-president, died at his home in Copper Cliff, Ontario. Dr. J. F. Thompson became vice-president; Dr. P. D. Merica, assistant to the president; J. C. Nicholls, assistant to the president at Toronto, Canada, and Donald McAskill, general manager at Copper Cliff.

Ore Reserves in Canada

The International Nickel Company of Canada, Limited, is supplied with almost unlimited ore. The situation of the Canadian nickel mines is probably unique. Practically all of the known deposits in the pre-Cambrian basin were located in the early days and acquired by different interests at that time. During the course of years and through various circumstances, these deposits have come into the possession of The International Nickel Company. The mineral exists in payable quantities in an area 40 miles long by 25 miles wide. Few new nickel mines have been discovered since 1860. The problem has been to choose from among many the mine which would yield the highest grade ore and develop the largest tonnage.

Many mines were opened until the discovery of the Creighton Mine in 1900, which, until the discovery of the Frood, was the most spectacular mine in the nickel area. In 1900 the Canadian Copper Company started work on a gossan-covered hill, north of a swamp which covered the ground now occupied by a great "Glory Hole." Diamond drills showed the presence of ore dipping under this hill. A shaft house was projected but in stripping away the peat at the base of the hill it was found to cover ore, so pits were dug through the swamp, further south, to find a site for the shaft house. Every pit revealed ore and finally it was found that this peat bog covered the largest deposit then known in the Sudbury district. Captain Lawson's report of November 7, 1900, showed the value of the property and a large shaft house was erected on the outcrop south of the swamp that winter. The mine was opened from the surface and quarried out during the first years. As the demand for ore increased and the rigors of winter would not permit continuous mining in the open pit, an underground development was begun. This mine has been one of the great mines of the North American Continent and supplied substantially all of the ore required by the International Nickel Company of New Jersey until the end of the war. It is still a large producer.

The largest known body of ore, the Frood Mine, is now nearing the stage of full production and has proved to be one of the richest, if not the richest mine of sulphide ore in the world, a noble successor to the Creighton Mine.

Published prices of metallic nickel from 1850 to 1888, before the rich Canadian deposits became known, show violent fluctuations. In 1873 the price of nickel reached a peak of $3.85 a pound. Discovery of the New Caledonia deposit brought the price down steadily over a period of 15 years and just before the Canadian production came on the market radical reduction brought the price of nickel to the lowest figure in all time, 16 cents a pound. This artificial price lasted only a short time and became re-established at 60 cents a pound when Colonel Thompson went abroad on his first trip to sell nickel. He made every effort to co-operate with the producers of nickel from New Caledonia ore to keep the price steady. We find the price maintained between 50 and 60 cents during the first years of Canadian production. From 1902 on, the published prices of nickel are surprisingly constant at 42 cents a pound, with a momentarily small increase during the World War. Fluctuations since the World War, due to a complete revision of the nickel industry, brought the price as low as 25 cents a pound, with a general average of about 35 cents or somewhat below the pre-war figure.

Summing up this brief history of The International Nickel Company, it is interesting to note that a period of only 42 years has elapsed since Colonel Thompson made his first delivery of nickel oxide to the steel makers.

The early days witnessed a curious crossing of paths from nickel to copper and back again. The start was, by choice, purely a nickel enterprise; in a few years, through necessity, it became a copper smelting business, and by the unexpected discovery of nickel in ores which were sold to the refiners as copper ores, reverted to a nickel enterprise. There was an involuntary crossing from nickel to copper and back again. Originally the name "Orford" was associated with nickel. Later it became identified with copper refining on the Atlantic Seaboard and only after a successful career in the copper field does the name appear again, associated with nickel.

The contradiction in names occurred in a similar way with the Canadian Copper Company, which started as a promising copper producer. Only through necessity were its activities centered on nickel.

Not until the consolidation of the two companies in 1902 did the principal business of both appear in the company name.

Until mining and refining interests were united in one company, the future was too uncertain for either company to puts its best effort into the development of a nickel industry. Once the two interests had been united a nickel industry was possible.

Since the World War, what was formerly a mining, smelting and refining business has become a world-wide nickel industry, with inexhaustible known nickel deposits, ready to supply the future; large natural power resources, smelters, refineries and rolling mills, producing a great variety of nickel products. For the distribution of these products, the Nickel Company's representatives are found in every continent of the globe, studying many fields for the use of nickel. Even more important than these are the increasing demands for nickel due to the widespread work of the engineering profession everywhere, in the search by industry for better and more dependable materials. The inquisitiveness of the engineer and his creative genius have brought to nickel a large and greatly diversified peace time market.

What was not so many years ago a mining company, smelting its ore and refining its matte for a limited nickel market, has become a vertically integrated world-wide industry, international in scope as well as in name.

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National Metal Congress

Fifty-five technical papers appear on the program which the American Society for Steel Treating has prepared for its sessions of the National Metal Congress in Boston, the week of September 21. This is the largest number of papers ever on an American Society for Steel Treating Program according to Ray T. Bayless, secretary of the Publication Committee of the Society.

National Metal Congress programs of the American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers and the American Welding Society will also be larger than usual, making the Congress greater and more instructive than ever before.

The National Metal Exposition will be located this year in the spacious Commonwealth Pier, conveniently near the Hotel Statler, headquarters of the American Society for Steel Treating, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers, and the Hotel Copley Plaza, chosen by the Welding Society as headquarters.

More than 200 firms have reserved space in the Exposition which will cover 60,000 square feet, almost twice as large as the 1930 show. The exhibits will display the latest equipment and products of the metal industry.

The American Society for Steel Treating technical program of the Congress lists the following papers:

Solubility of Oxygen in Solid Iron. N. A. Ziegler.

Hardness of Chromium as Determined by the Vickers-Brinell Bierbaum, and Mohs Methods. Richard Schneidewind.

Dendrites in Nickel Steel. Albert Sauveur and E. L. Reed.

The Characteristics of Deformation of Steel under Constant Load at Elevated Temperatures. G. R. Brophy.

Some New Aspects of the Iron-Carbon Diagram. H. A. Schwartz.

Correlation of the Crystal Structures and Hardnesses of Nitrided Cases. O. E. Harder and G. B. Todd.

The Resistance to Wear of Carbon Steels. S. J. Rosenberg.

Endurance Properties of Some Well-Known Steels in Steam. T. S. Fuller.

Corrosion Resistant Steels. R. L. Duff.

Surface Energy of Iron Carbide. Yap Chu-Phay.

Comparison of Sheet and Strip Steels for Difficult Stampings. Edw. S. Lawrence.

Nature of Abnormal Grain Growth in High Speed Steel. G. R. Brophy and R. H. Harrington.

Aging in Low-Carbon Steels. A. Allan Bates.

Cemented Tantalum Carbide. Floyd C. Kelley.

Nondeforming Alpha-Delta Carburizing Steel. A. B. Kinzel.

Behavior of Some Irons and Steels under Impact at Low Temperatures. Robert Sergeson.

Influence of Grain Size on the Properties and Corrosion Re-

sistance of the 18-8 Iron-Chromium-Nickel Alloy for Elevated Temperature Service. H. D. Newell.

Plastic Drawing of Sheet Steel into Shapes. E. V. Crane.

Short-Time Nitriding. J. J. Egan.

Scaling of Steel at Elevated Temperatures by Reaction with Gases and the Properties of the Resulting Oxides. D. W. Murphy, Wm. P. Wood and W. E. Jominy.

Thin Strip Steel for Deep Drawing. H. T. Morton and I. A. Rummler.

Some Physical Properties of High Speed Steel. J. V. Emmons.

Thermomagnetic Phenomena in Steel. R. L. Sanford.

The Cold Treatment of Certain Alloy Steels. G. V. Luerssen and O. V. Greene.

Characteristics of Alloyed Cast Iron. F. W. Shipley.

Impact Characteristics of Steel Rails at Low Temperatures. J. F. Cunningham and James Gilchrist.

Manufacture, Properties and Uses of 18-8 Chromium-Nickel Steel Wire. W. H. Wills and J. K. Findley.

Precious Metal Alloys. R. C. Brumfield.

Identification of Inclusions. Leland E. Grant.

Effect of Heat Treatment upon Ferrite Banding of Steel. W. E. Harvey and Bradley Stoughton.

Effect of Normalizing upon the Grain Structure and Physical Properties of Automobile Sheet Steel. Wm. F. McGarrity and H. V. Anderson.

Influence of Special Elements on the Carbon Content of the Iron-Carbon Eutectoid. E. L. Reed.

Further Studies on Chromium-Nickel-Iron and Related Alloys. V. N. Krivobok, E. L. Beardman, H. J. Hand, T. O. A. Holm, A. Reggiori and H. S. Rose.

Inspection of Welds with Gamma Rays. Gilbert E. Doan.

Alloys of Iron, Manganese and Carbon. F. M. Walters.

The Role of Energizers in Carburizing Compounds. George M. Enos.

Tool Steel from the Consumers' Standpoint. H. G. Keshian.

Melting of Tool and Other High Grade Steels in the Basic Electric Furnace. J. P. Gill and R. E. Trembour.

Ghost Lines in Forgings. J. F. Harper and H. J. Stein.

Age Hardening Phenomena in Typical Fusion Weld Metal. F. R. Hensel and E. J. Larsen.

Open Hearth Process. C. H. Herty, Jr.

Aqueous Solutions of Ethylene Glycol Glycerine and Sodium Silicate as Quenching Media. T. E. Hamill.

Melting of Crucible Tool Steel. Owen K. Parmiter.

Lubricants Used in Deep Drawing of Sheet Steel. Maurice Reswick.

Data on Steel Made without Manganese. Captain S. B. Ritchie.

Some Effects of the Amount and Rate of Deformation on a Low Carbon Strip Steel. Joseph Winlock and A. E. Lavergne.

Making of Acid Electric Steel for Castings. George Batty.

Ingots, Ingot Molds and Castings. G. A. Dornin.

Thermomagnetic Investigations of Tempering of Quenched 0.75 Percent Carbon Steel. C. A. Ellinger.

Division of the Iron–Vanadium–Oxygen System into Some of Its Constituent Binary and Ternary Systems. C. H. Mathewson, E. Spire and C. H. Samans.

Magnetic and Mechanical Hardness of Dispersion Hardened Iron Alloys. K. S. Seljesater and B. A. Rogers.

Development of Italian Industry Making Special Steels and Irons. Federico Giolitti.

Photomicrographs of Steels with One Percent Carbon Arranged in Graded Series for Use as Standard. Haakon Styri and H. O. Walp.

The Evaluation of the Drawing Quality of Extra Deep Drawing Sheets. Thomas Dockray.

Abstracts of these papers will appear in the abstract section of METALS & ALLOYS.

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Meeting of the International Association for Testing Materials

The First Congress of the New International Association for Testing Materials will be held in the Federal Polytechnicum in Zurich from September 7 to 12, 1931.

The program of the paper, which will interest metallurgical engineers, is listed below. Abstracts of the papers will appear in the abstract section of METALS & ALLOYS.

CAST IRON

The Structure and Mechanical Properties of Cast Iron. J. G. Pearce.

Der Grauguss und seine Prüfmethoden. E. Piwowarsky.

Caractérisation des Propriétés mécaniques des Pièces moulées en Fonte grise. A. Portevin.

Tests on Cast Iron. A Consideration of Test Results Obtained in Czechoslovakia. F. Pisek.

Beitrag zu der Frage der Prüfungsverfahren für Gusseisen. E. Dübi.

STRENGTH OF METALS AT HIGH TEMPERATURES

Les Métaux aux Températures élevées. J. Galibourg.

Abkürzungsverfahren zur Bestimmung der Dauerstandfestigkeit des Stahles. A. Pomp & W. Enders.

Materials at High Temperatures. R. G. Batson & H. J. Tapsell.

FATIGUE

Ermüdung. P. Ludwik.

The Present State of Knowledge of Fatigue of Metals. H. J. Gough.

Fatigue. D. J. McAdam, Jr.

L'Essai aux Chocs répétés à Flexion alternée sur les Rails des Chemins de fer italiens Essais de Torsion alternée de 360° sur Fils de Cables métalliques pour Voies ferrées aériennes et Funiculaires. P. Forcella.

Über die Entwicklung der Dauerprüfung in Deutschland. E. Schulz & H. Buchholtz.

NOTCHED-BAR IMPACT TEST

Der Stand der Kerbschalgproben-Frage in Deutschland. M. Moser.

Essais au Choc sur Barreaux entaillés. R. Zoja.

Kerbschlagproben, Normenprobe. M. Schmidt.

Meaning of the Notched-Bar Impact Test for Investigation and for Acceptance Test Purposes. R. H. Greaves.

L'Essai de Résilience comme Essai de Réception. A. Steccanella.

PROGRESS OF METALLOGRAPHY

Advances in Microscopy. F. F. Lucas.

Progress of the Knowledge Regarding Slag Inclusions in Iron and Steel. C. Benedicks & H. Löfquist.

Progress of Metallography. J. L. Haughton.

Die neuere Entwicklung der Konstitutionsforschung der Legierungen. W. Guertler.

X-Ray Investigations of the Constitution of Alloys. A. Westgren.

CALIBRATION AND ACCURACY OF TESTING MACHINES

The Calibration of Testing Machines. H. F. Moore.

Accuracy of Measurement and Variability of Test. F. C. Lea.

Eichung und Genauigkeit von Prüfmaschinen. W. Ermlich.

FUNDAMENTAL AND TEST RELATIONS BETWEEN ELASTICITY AND PLASTICITY, TOUGHNESS AND BRITTLENESS

Begriffliche und prüfmethodische Beziehung zwischen Elastizität und Plastizität, Zähigkeit und Sprödigkeit. M. Ros & A. Eichinger.

Relations entre l'Elasticité et la Plasticité, la Ténacité et la Fragilité. Moyens pratiques de les caractériser. P. Regnauld.

Elastizität und Plastizität, Zähigkeit und Sprödigkeit. G. Sachs.

Ideal and Practical (Test) Relations between Elasticity and Plasticity, Tenacity and Brittleness. F. B. Seely.

Begriffliche und prüfmethodische Beziehung zwischen Elastizität, Plastizität, Zähigkeit und Sprödigkeit. A. Schob.